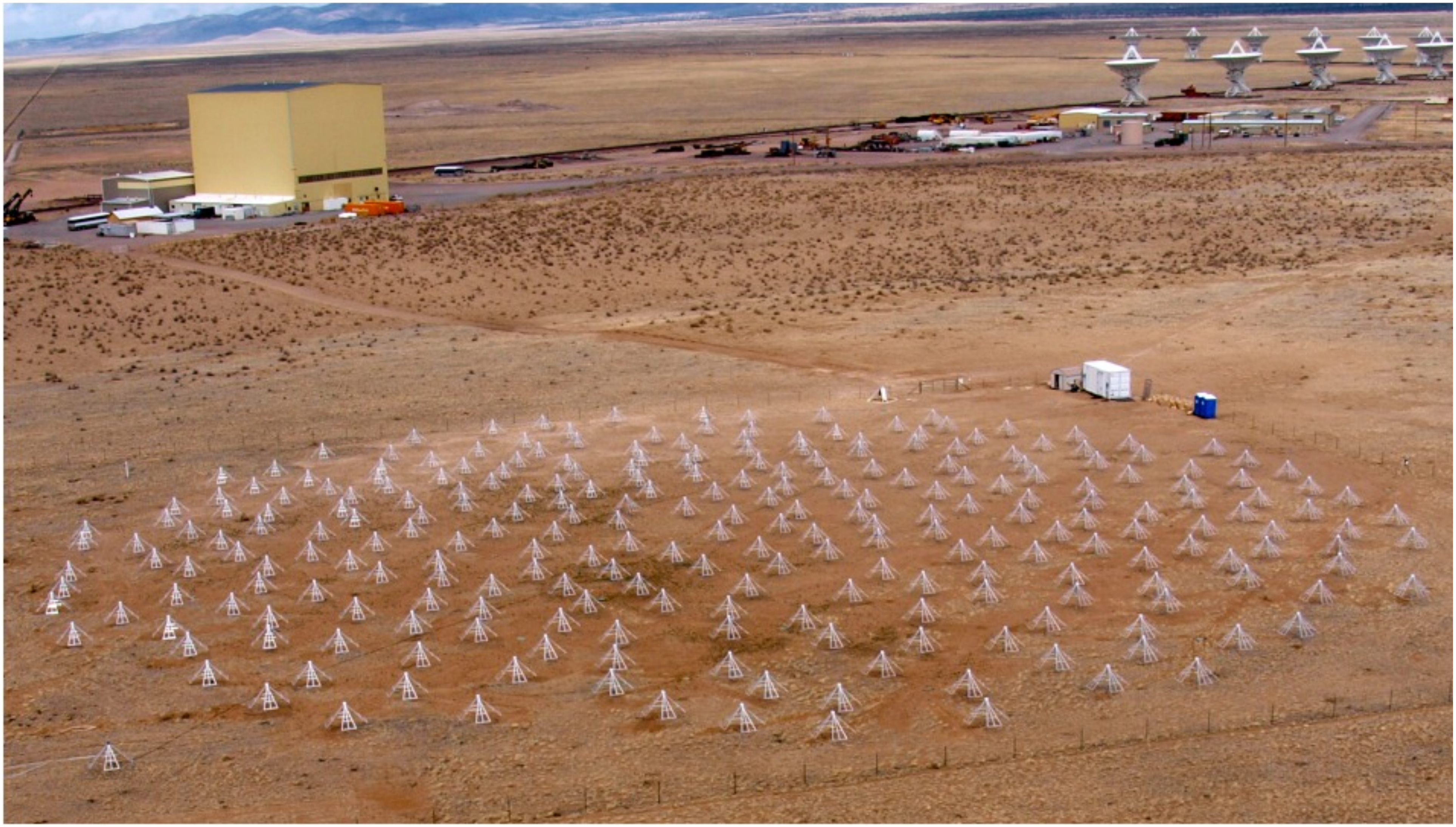
Science at Low Frequencies with the Long Wavelength Array

Greg Taylor (UNM)
On behalf of the LWA Collaboration

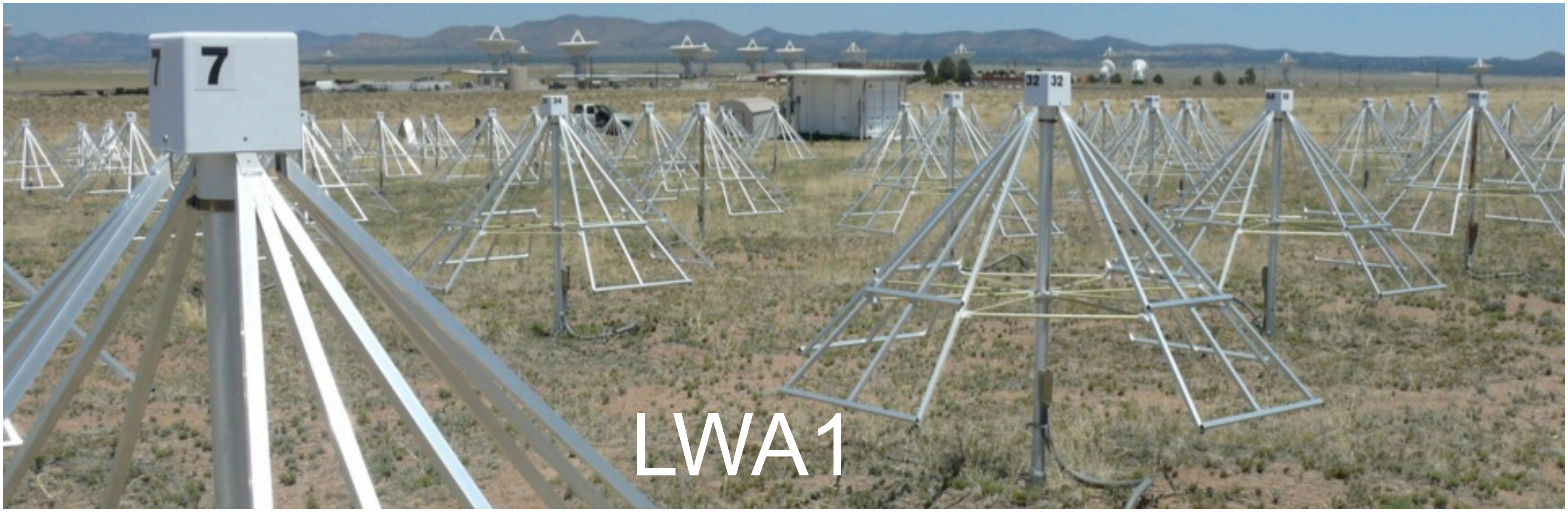
ASU, 3/29/2017

Science at Low Frequencies II, held in Albuquerque NM Dec 2-4, 2015. 105 attendees from around the world.

Follow-up from SLF I in Tempe (2014)



LWA1



10-88 MHz usable Galactic noise-dominated (>4:1) 24-87 MHz

4 independent beams x 2 pol. X 2 tunings each ~16 MHz bandwidth

All sky (all dipoles) modes: TBN (70 kHz-bandwidth; continuous)

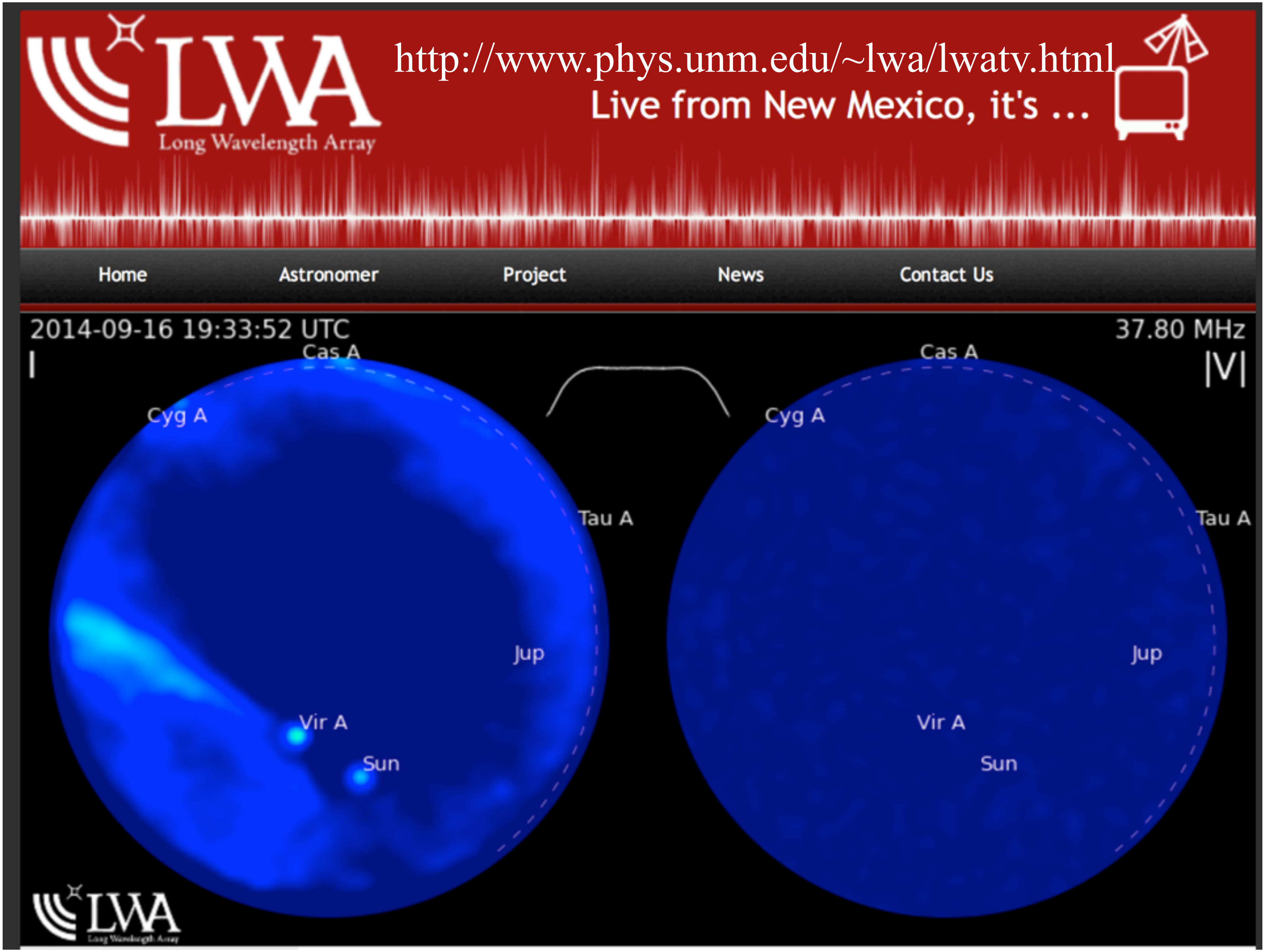
TBW (78 MHz-bandwidth, 61 ms burst)

World class facility, now observing jointly with VLA

Five “outrigger” antennas at up to 500 m baselines

LWA1 discoveries: meteors, pulsars, Sun, Jupiter & Ionosphere

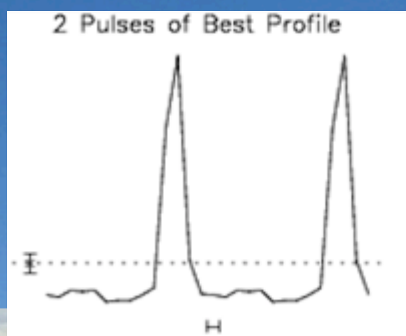
Open skies – LWA1 is funded by NSF as a University Radio Observatory

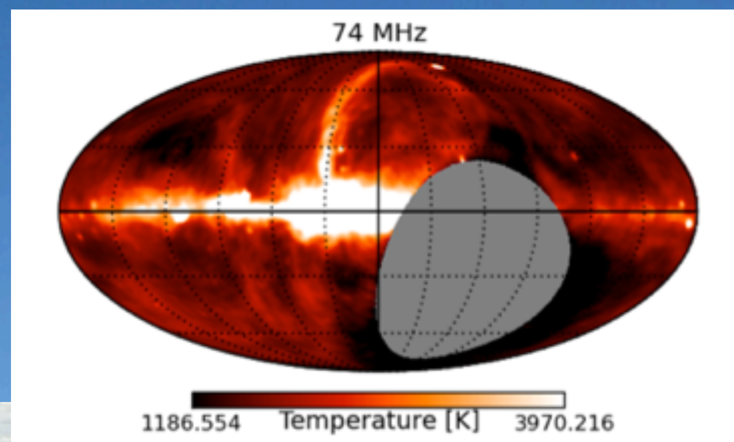


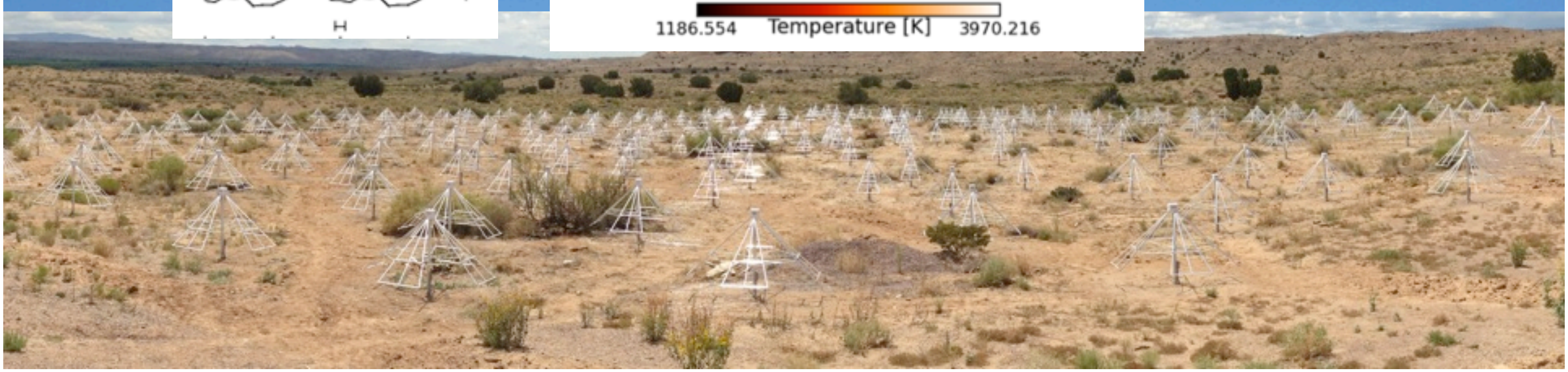
LWA
Long Wavelength Array
http://www.phys.unm.edu/~lwa/lwatv.html
Live from New Mexico, it's ...
Home
Astronomer
Project
News
Contact Us
2014-09-16 19:33:52 UTC
37.80 MHz
I
|V|
Cas A
Cyg A
Tau A
Jup
Vir A
Sun
Cas A
Cyg A
Tau A
Jup
Vir A
Sun
LWA

LWA-SV station

- New station as part of the Long Wavelength Array
- 257 dual polarization LWA dipoles
- 20 MHz bandwidth beamforming
- 20 MHz bandwidth all-sky imaging
- 70 km baseline provides 10” resolution in conjunction with LWA1





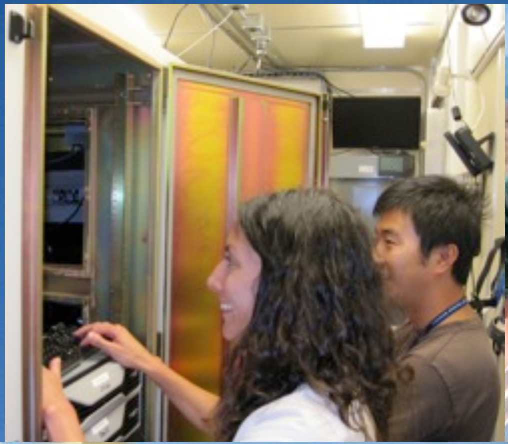


LWA Technology

Construction

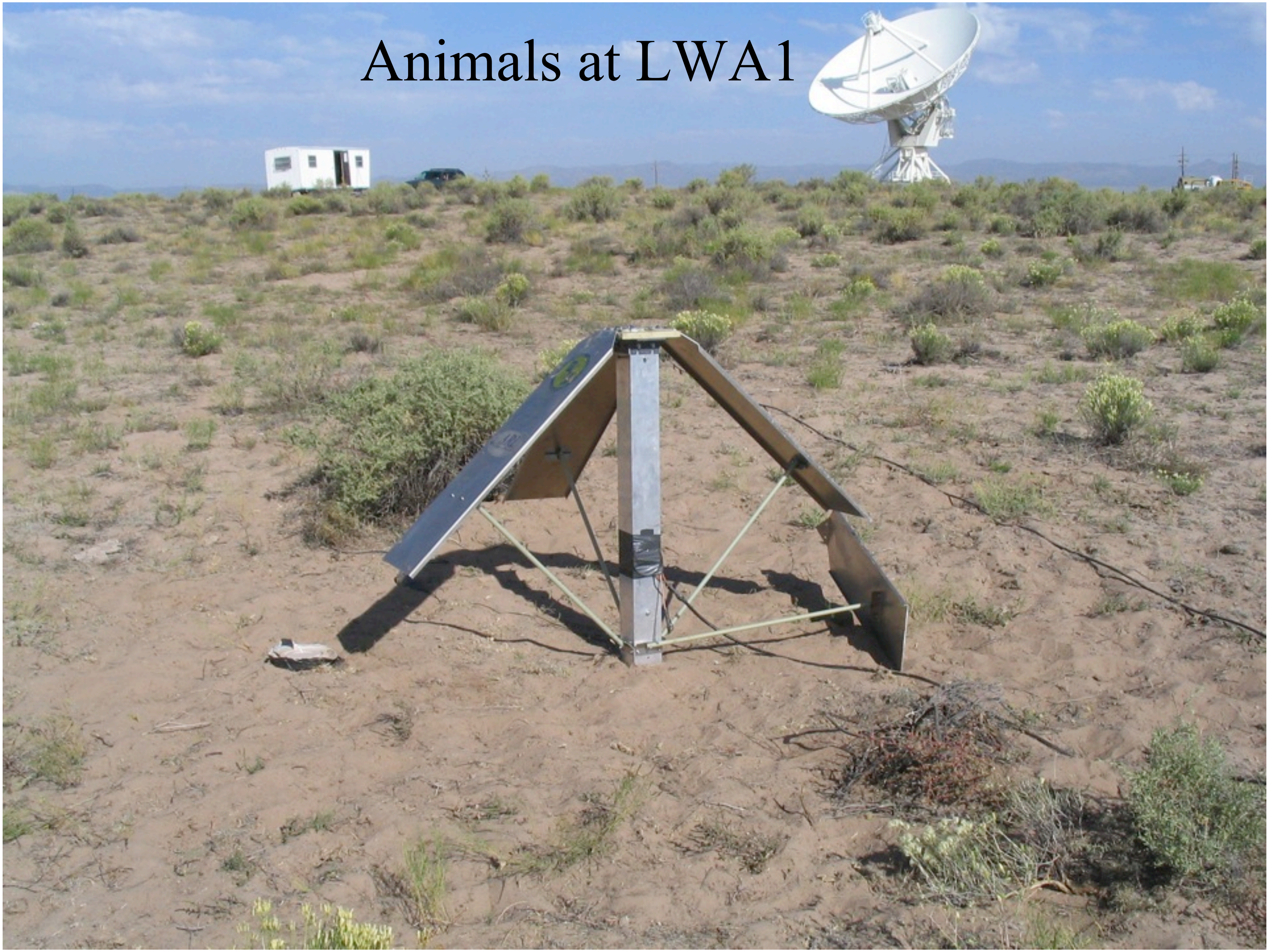
- Site/Power/Coms/Shelter
- Trenching & Conduit for Cabling
- Antenna Installation
- Cable Installation

- Receivers, Digital Processor, Data Recorders, Electronics



How to Build an LWA antenna

Animals at LWA1



Animals at LWA1

Natural Hazards

LWA Science

Astrophysics

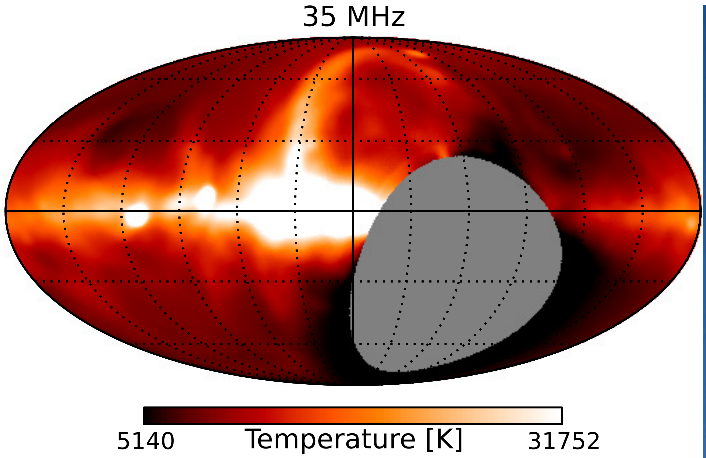
- **Cosmology**
  Observing cosmic dawn through redshift 30 absorption of the 21 cm line. High redshift radio galaxies, containing the earliest black holes
- **Acceleration, Propagation & Turbulence in the ISM**
  Origin, spectrum & distribution of Galactic cosmic rays, Supernova remnants & Galactic evolution, Pulsars and their environments
- **Solar Science & Space Weather**
  Jupiter, Radio heliography of solar bursts & coronal mass ejections, Solar magnetic fields
- **Exploration of the Transient Universe**
  New coherent sources, GRB prompt emission, poorly explored parameters space …
- **Meteors**
  Self-emission and reflections of man-made signals

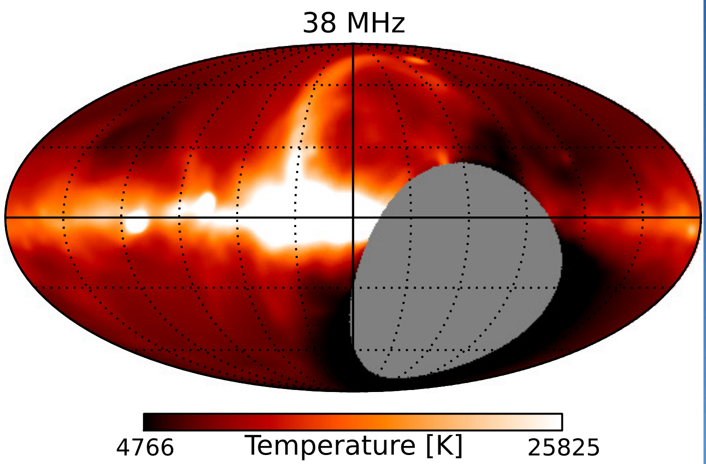
Iono- & Atmospheric Physics

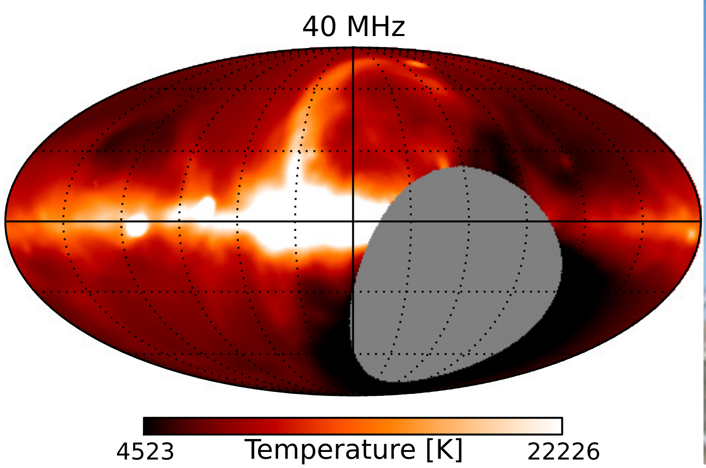
- Unprecedented continuous spatial & temporal imaging of the ionosphere
- Test and improve global ionospheric models
- High-time-resolution Imaging of Lightning

Cosmic Ray Physics

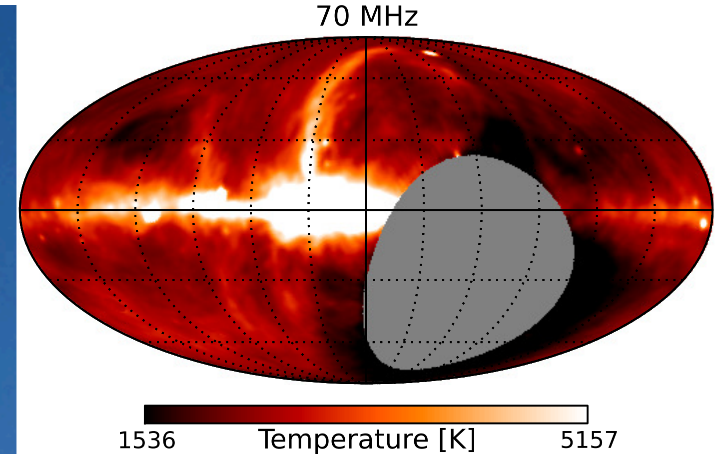
Your ideas?
All of LWA1 time is open skies.
Your observing proposals are welcome!

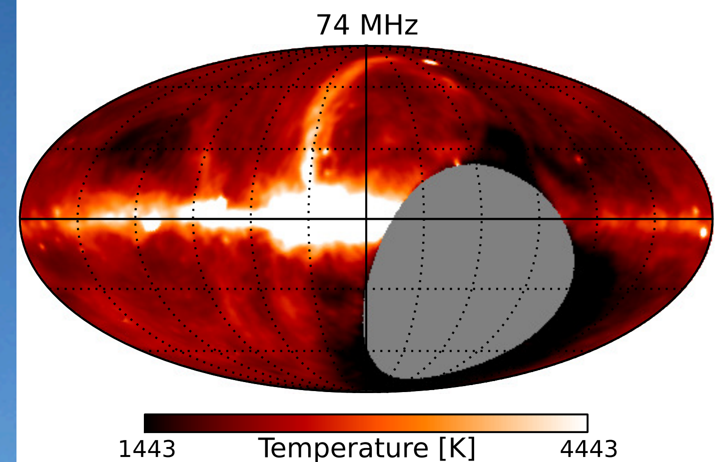

35 MHz
5140
Temperature [K]
31752

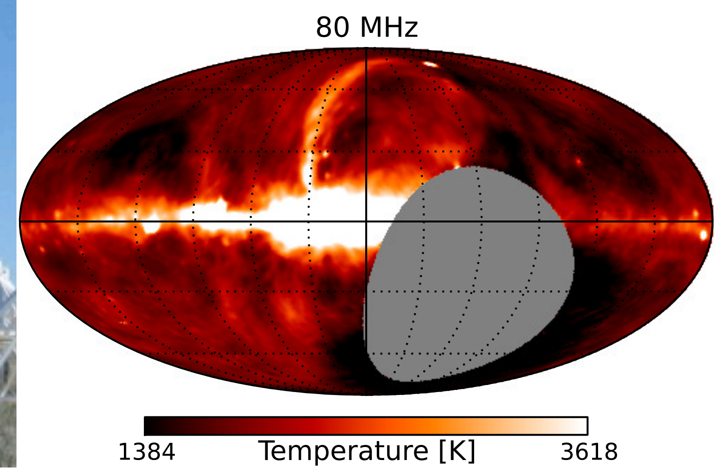

38 MHz
4766
Temperature [K]
25825


40 MHz
4523
Temperature [K]
22226

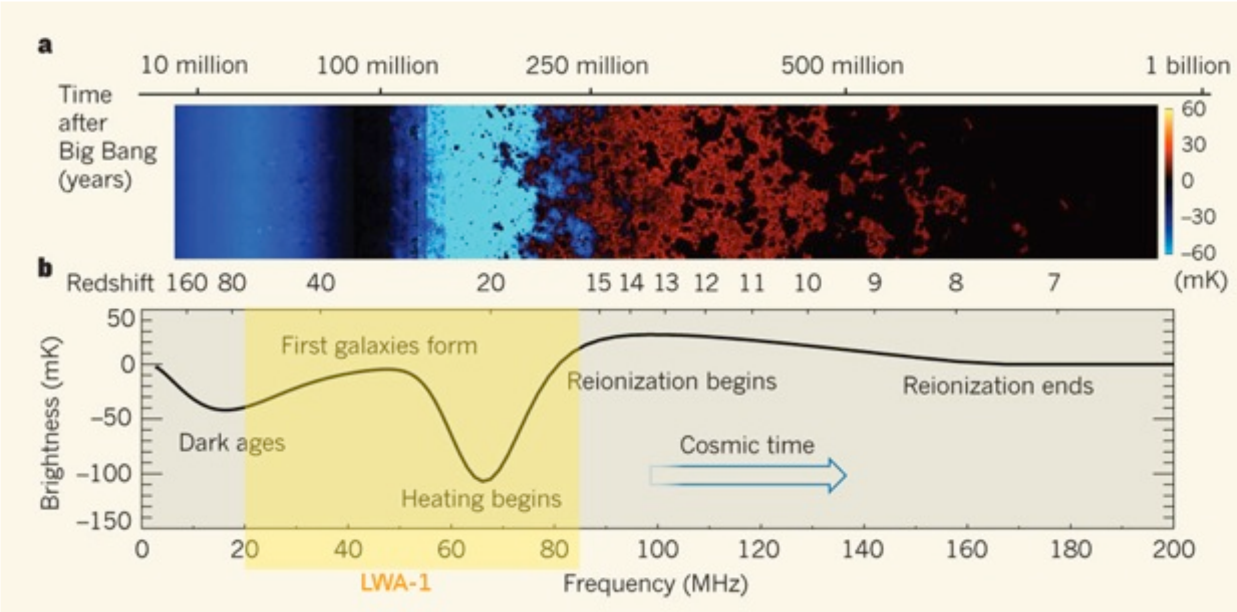

The Sky
35-80 MHz
Dowell et al.
2017
+ New Low
Frequency Sky
Model generator


70 MHz
1536
Temperature [K]
5157


74 MHz
1443
Temperature [K]
4443


80 MHz
1384
Temperature [K]
3618

LWA 1 Science Program: Dark Ages



The predicted brightness temperature of the 21cm line from the HI gas is displayed as a function of time, redshift & frequency.

Figure 1 from Pritchard & Loeb, 2010 Nature 469 772

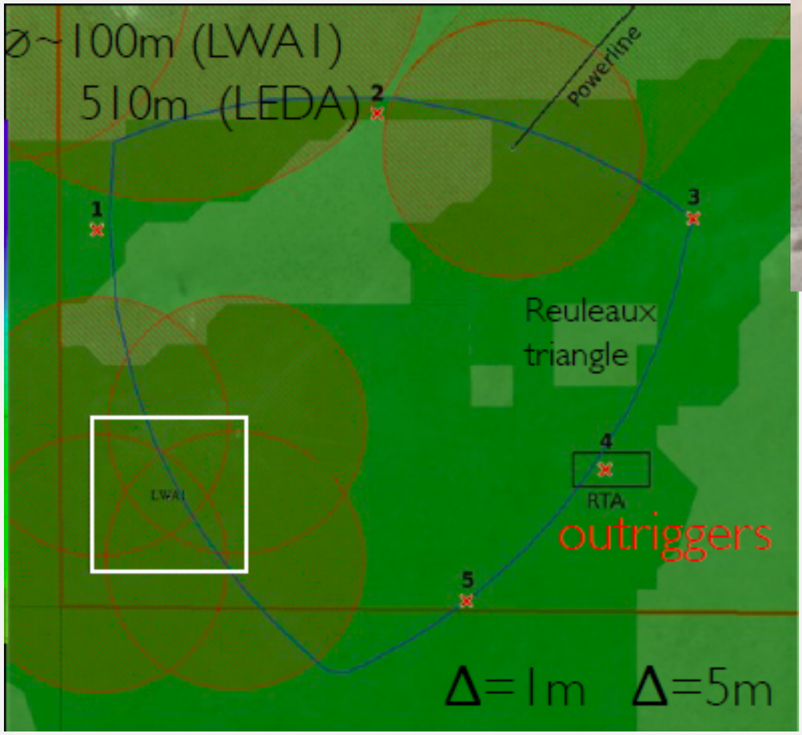
The Dark Ages through Cosmic Dawn encompasses the formation of the 1st galaxies & black holes. LWA1 offers a unique window into this era.

- ***LEDA*** (PI Greenhill): Constrain Dark Ages signal
  - Probe thermal history & Lyα output of 1st stars & galaxies by characterizing HI trough – only means to detect IGM @ z >15
  - New correlator, total power hardware & data reduction pipeline

LWA Long Wavelength Array

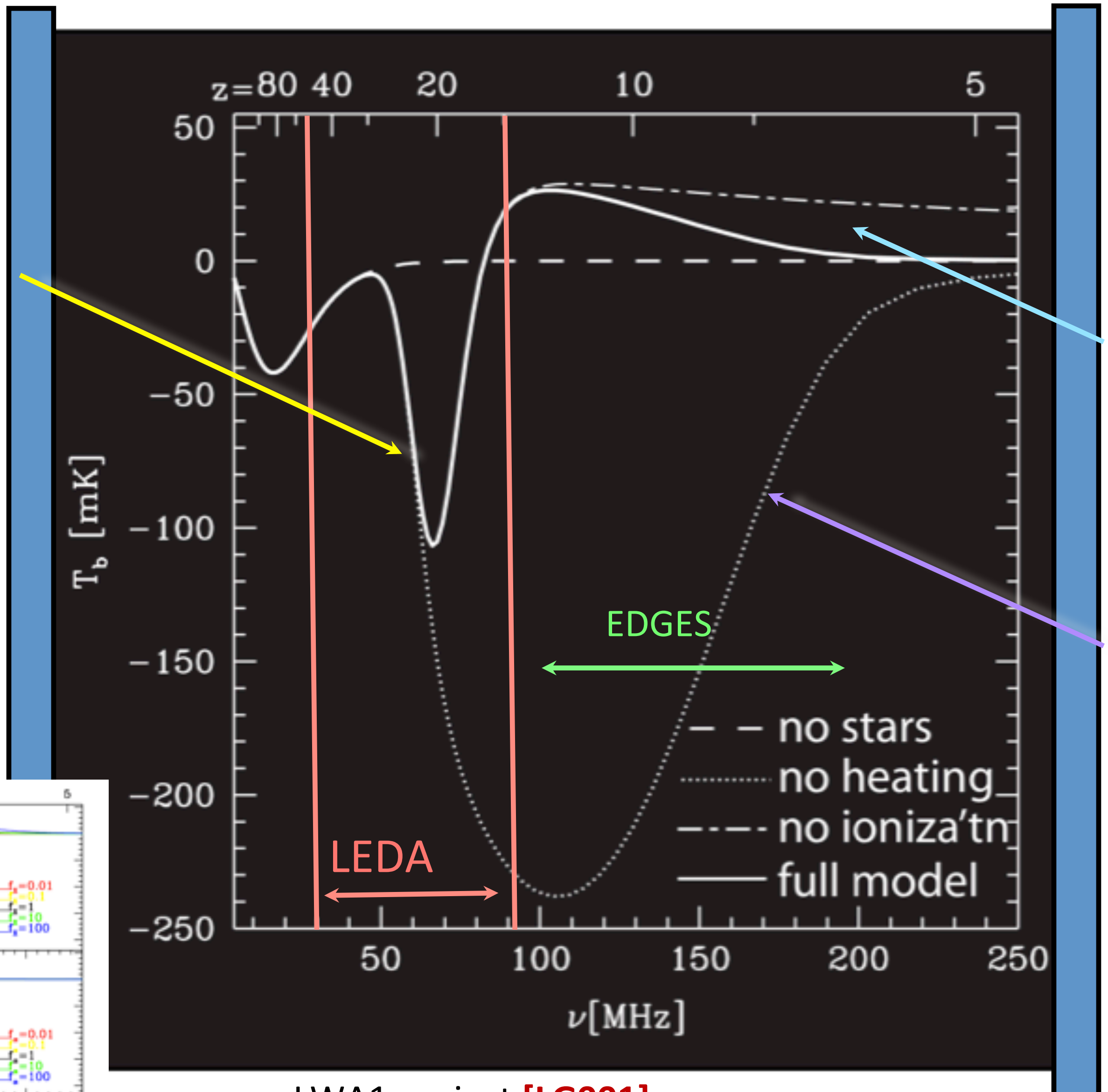
LEDA –outriggers for LWA1

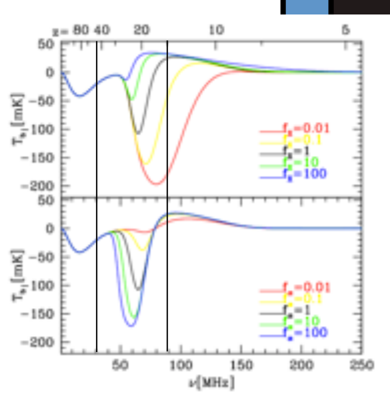
Construction of 4 additional outriggers.



LEDA: Inference

Lyman-α photon production (likely from stars) determines magnitude of decoupling from the dashed curve

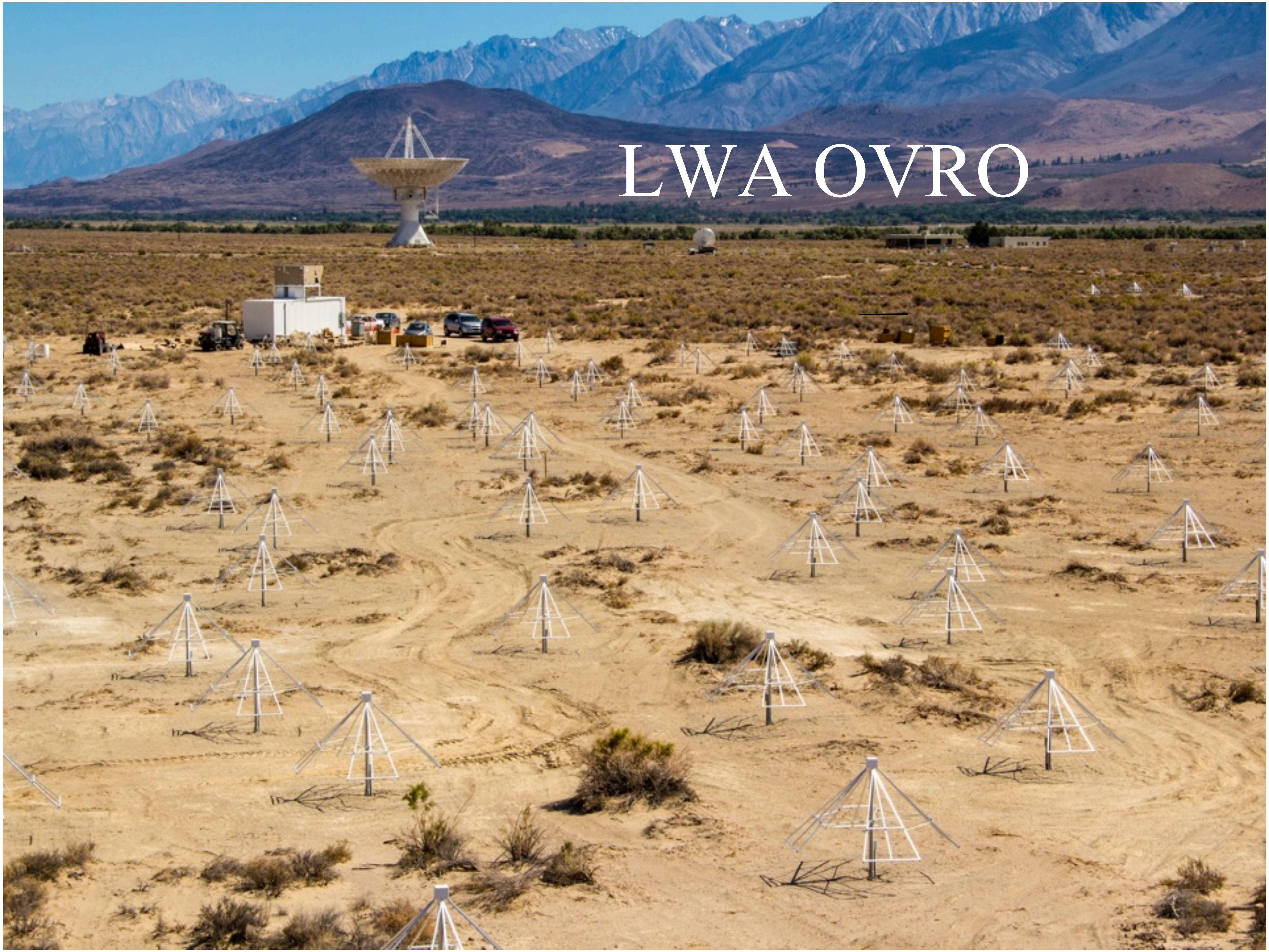




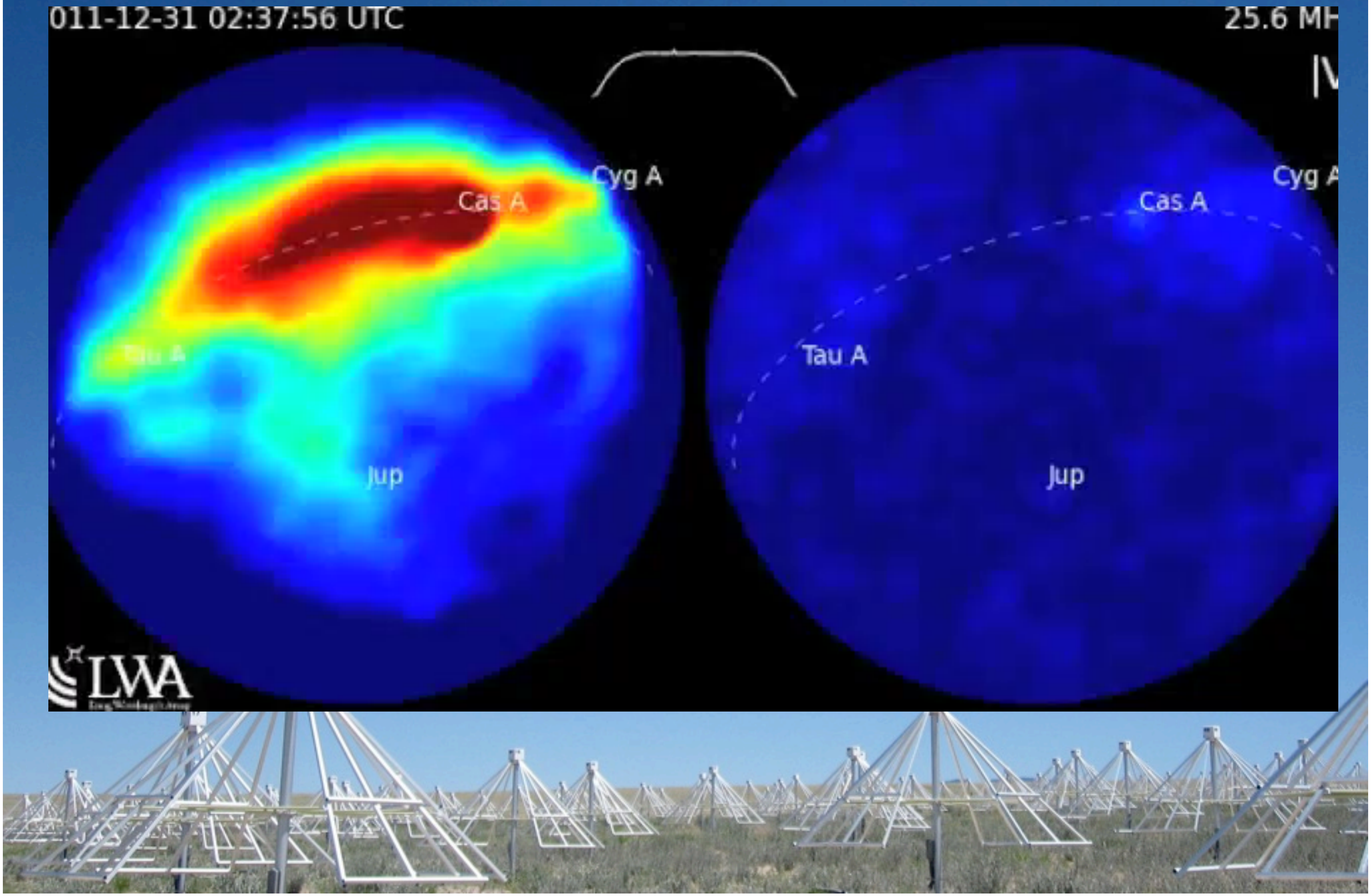
LWA1 project **[LG001]**

Production of ionizing photons determines the difference between dash-dot and solid curves

Case where IGM not reheated prior to reionization. It takes just 10^{-3} eV per baryon to significantly change this curve.

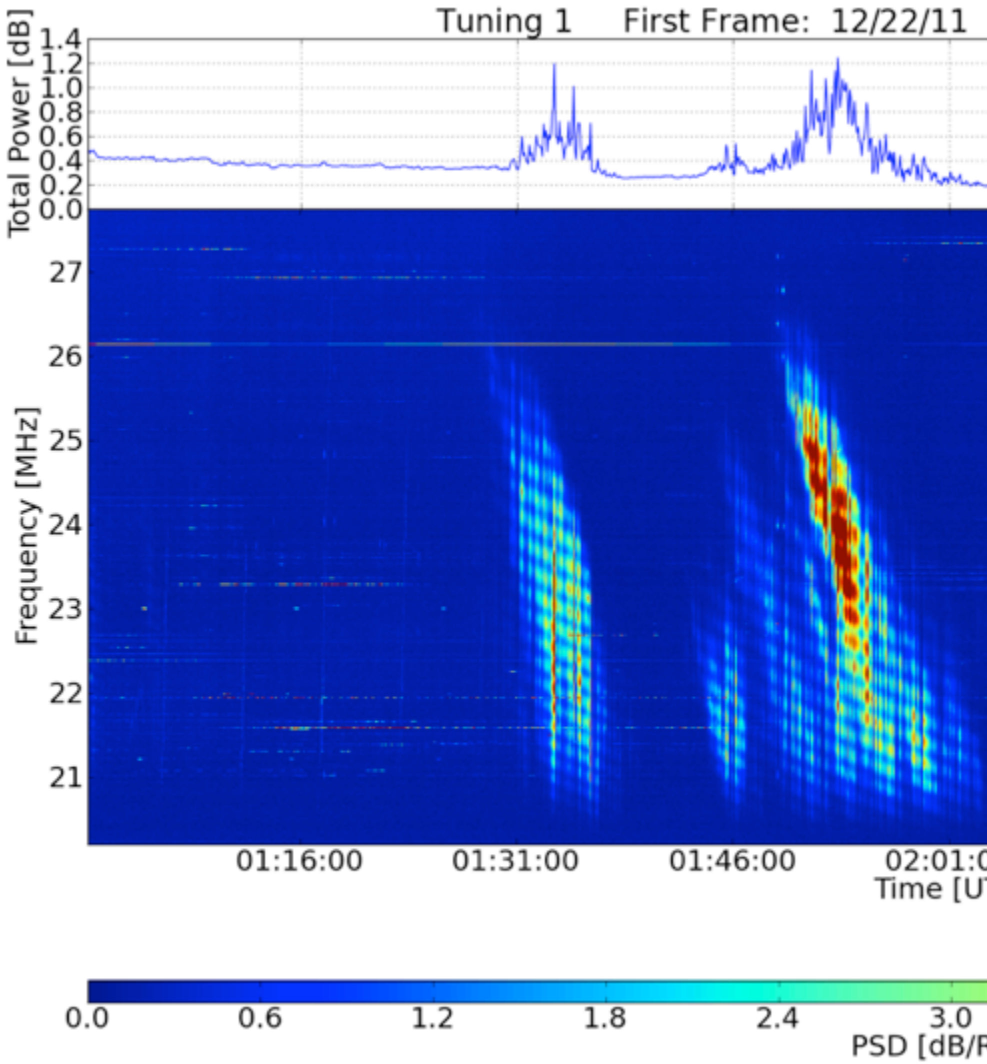

LWA OVRO

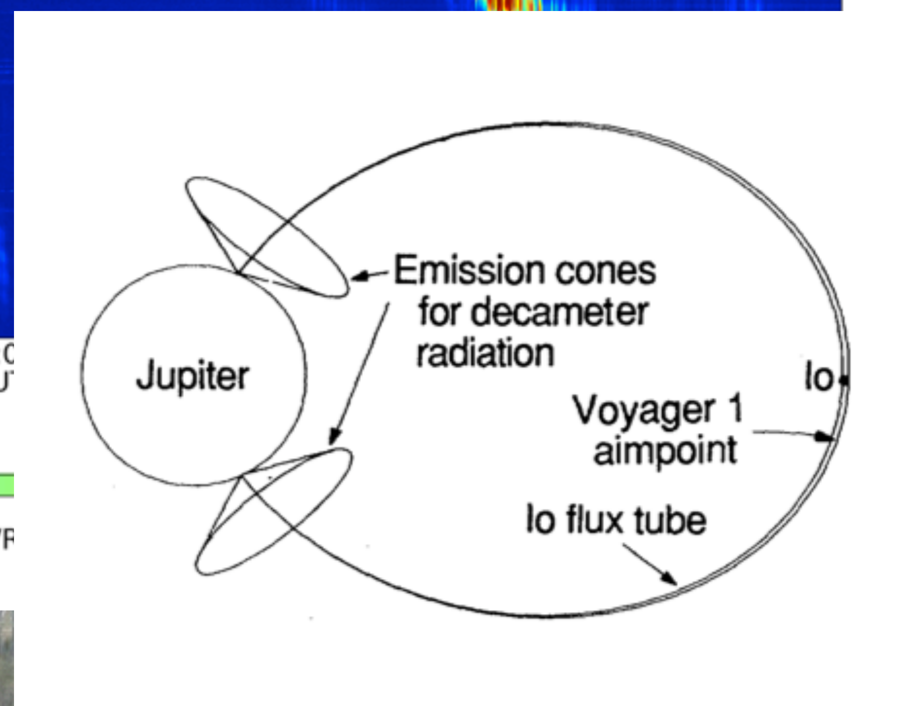
Jupiter



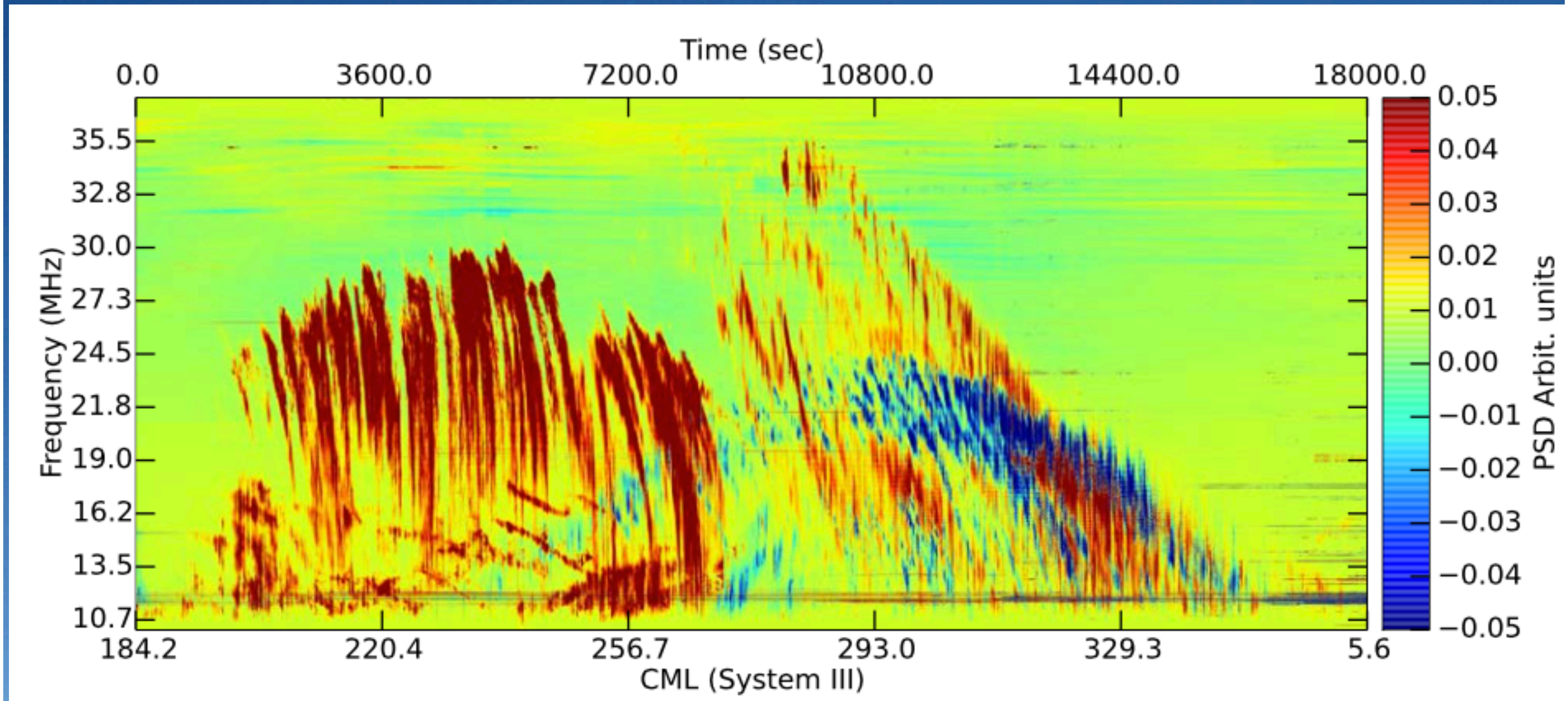
011-12-31 02:37:56 UTC
25.6 MH
Cyg A
Cas A
Tau A
Jup
Cyg A
Cas A
Tau A
Jup
LWA

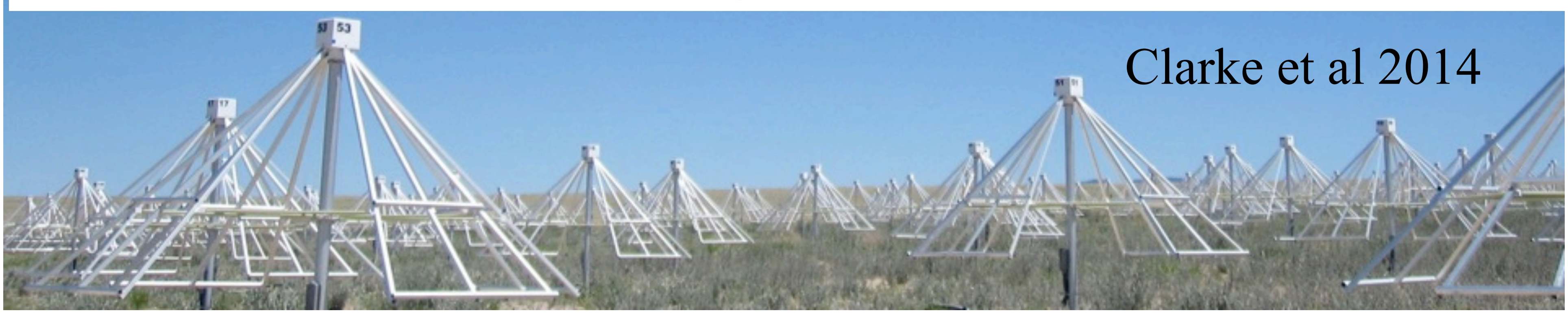
Decametric Jovian Emission





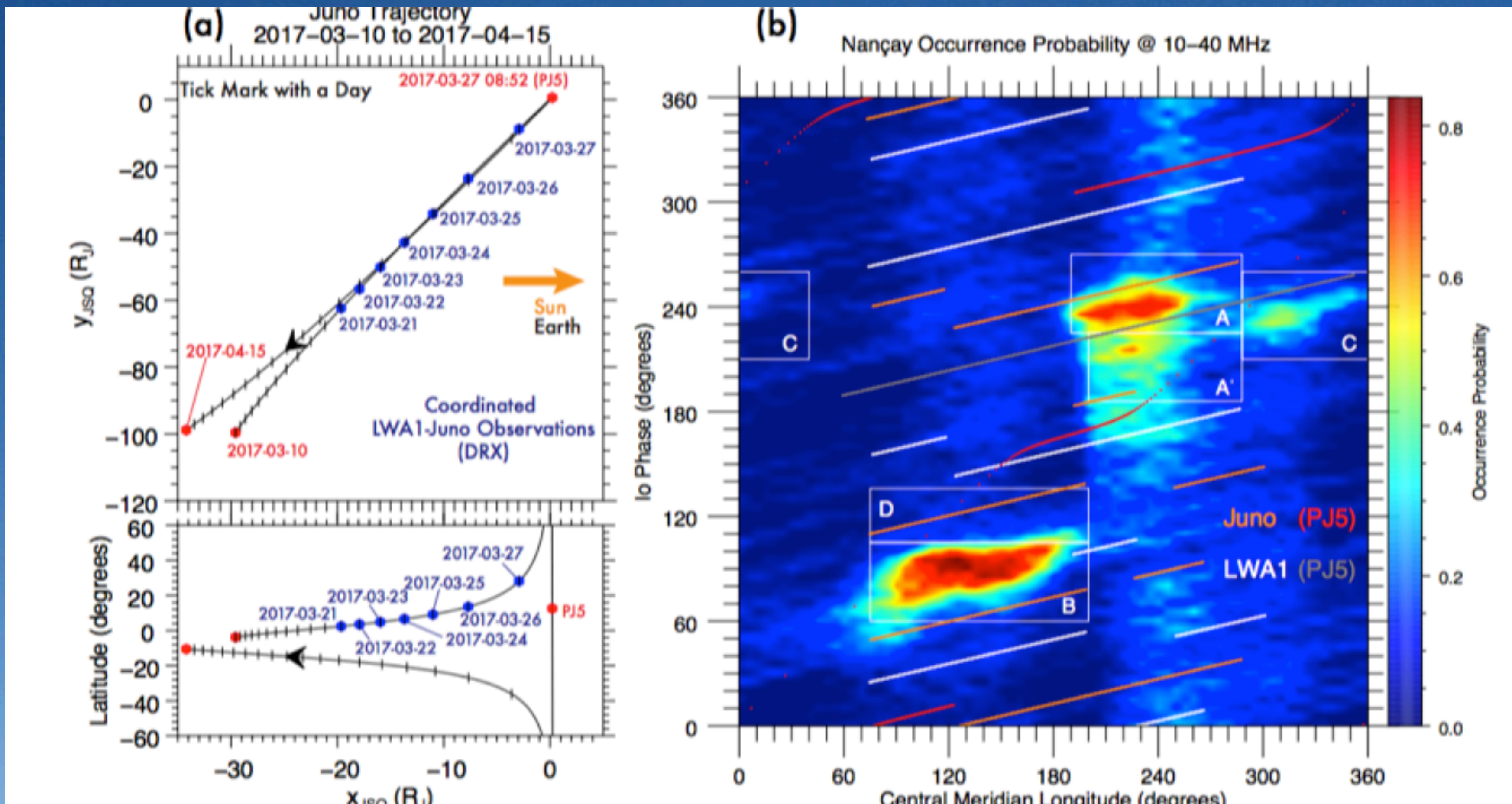
Jupiter





Clarke et al 2014

Juno at Jupiter

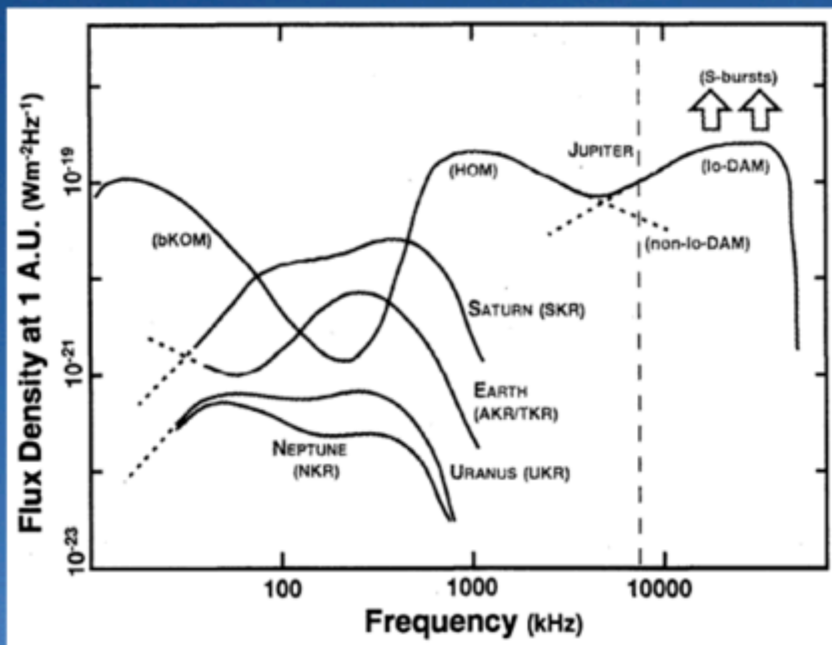


Exoplanets

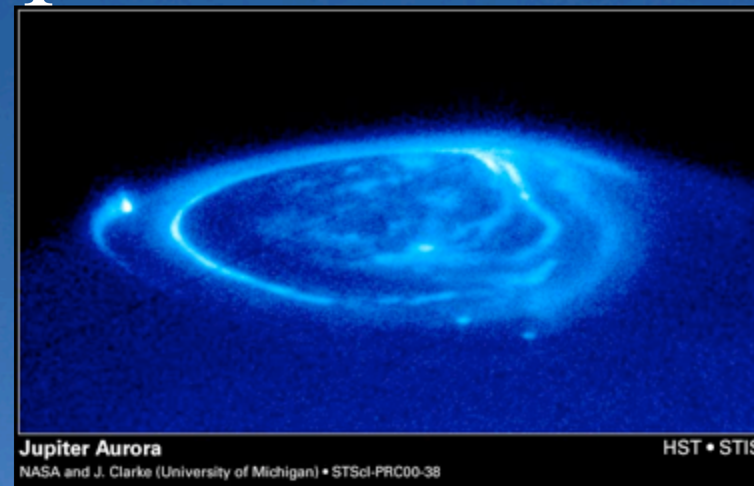
- Possibility of detecting exoplanets and exomoons
- Allows measurement of the magnetic field strength and rotation periods
- How strong is the emission?
  - Jupiter bursts are up to 1 GigaJansky at 5 AU
  - Expect ~6 milliJy signal at 30 MHz at 10 parsecs

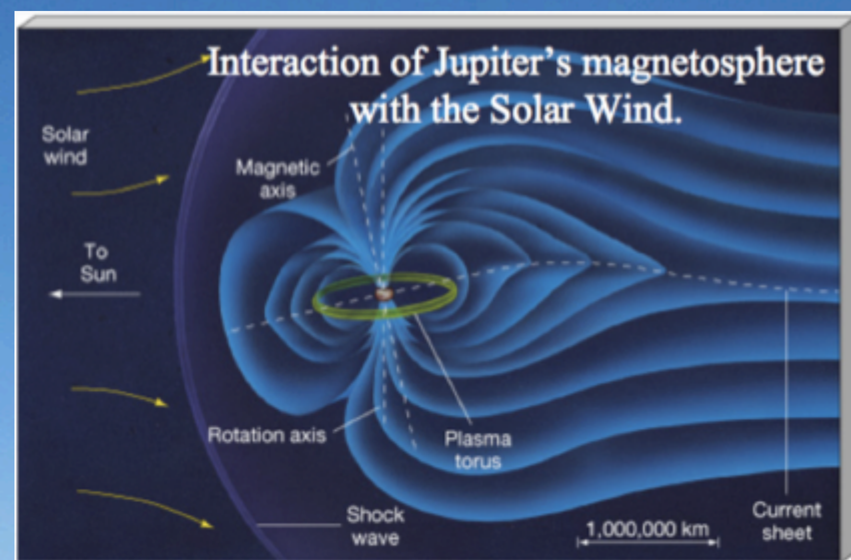
- But how exceptional is Jupiter?

From our Jupiter …

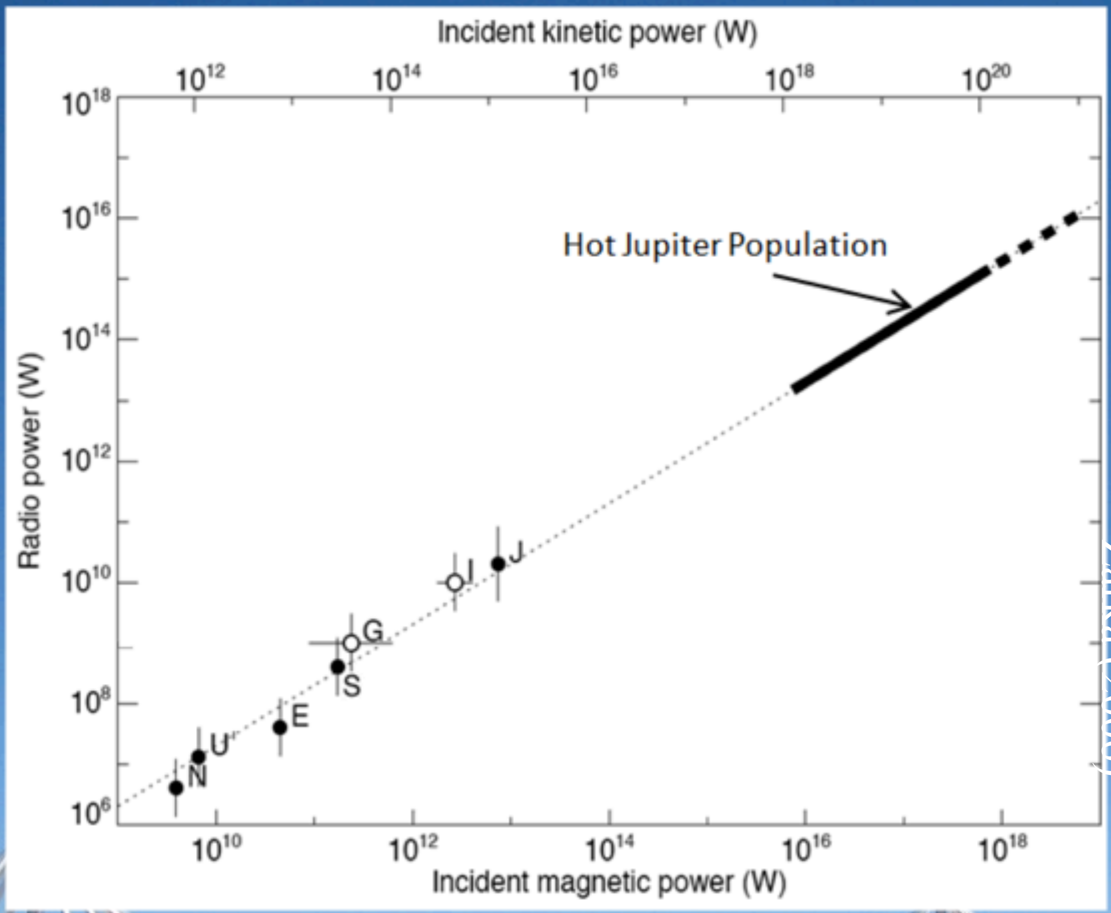


Zarka (1998)





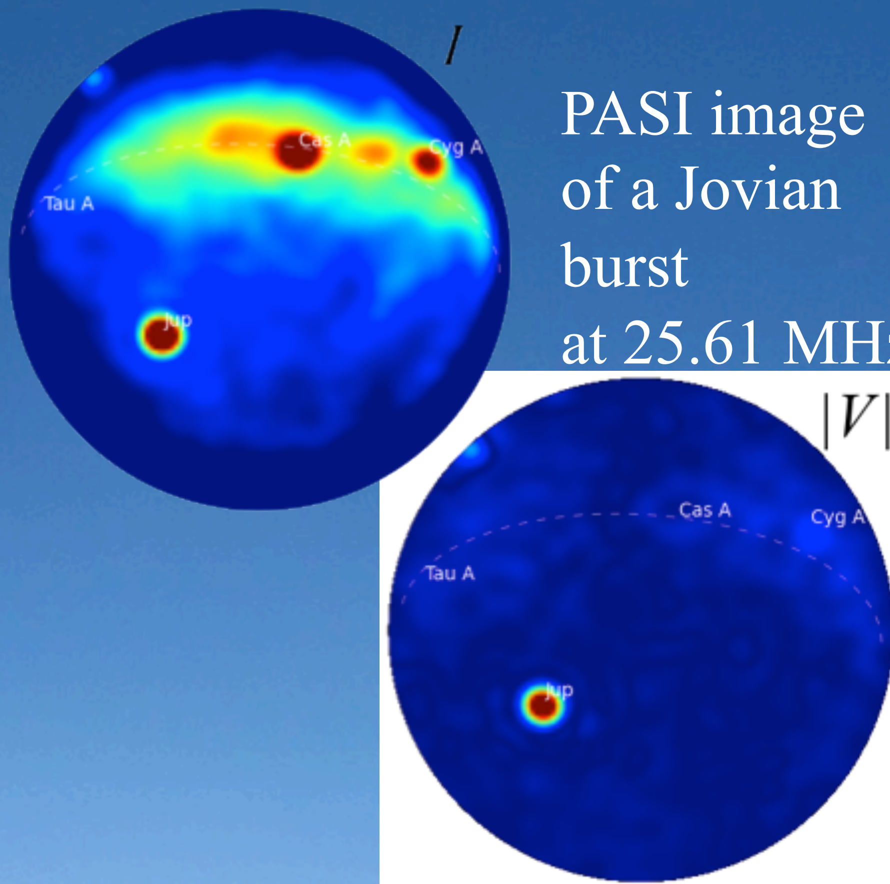
… Extrapolating to Hot Jupiters



Zarka (2006)

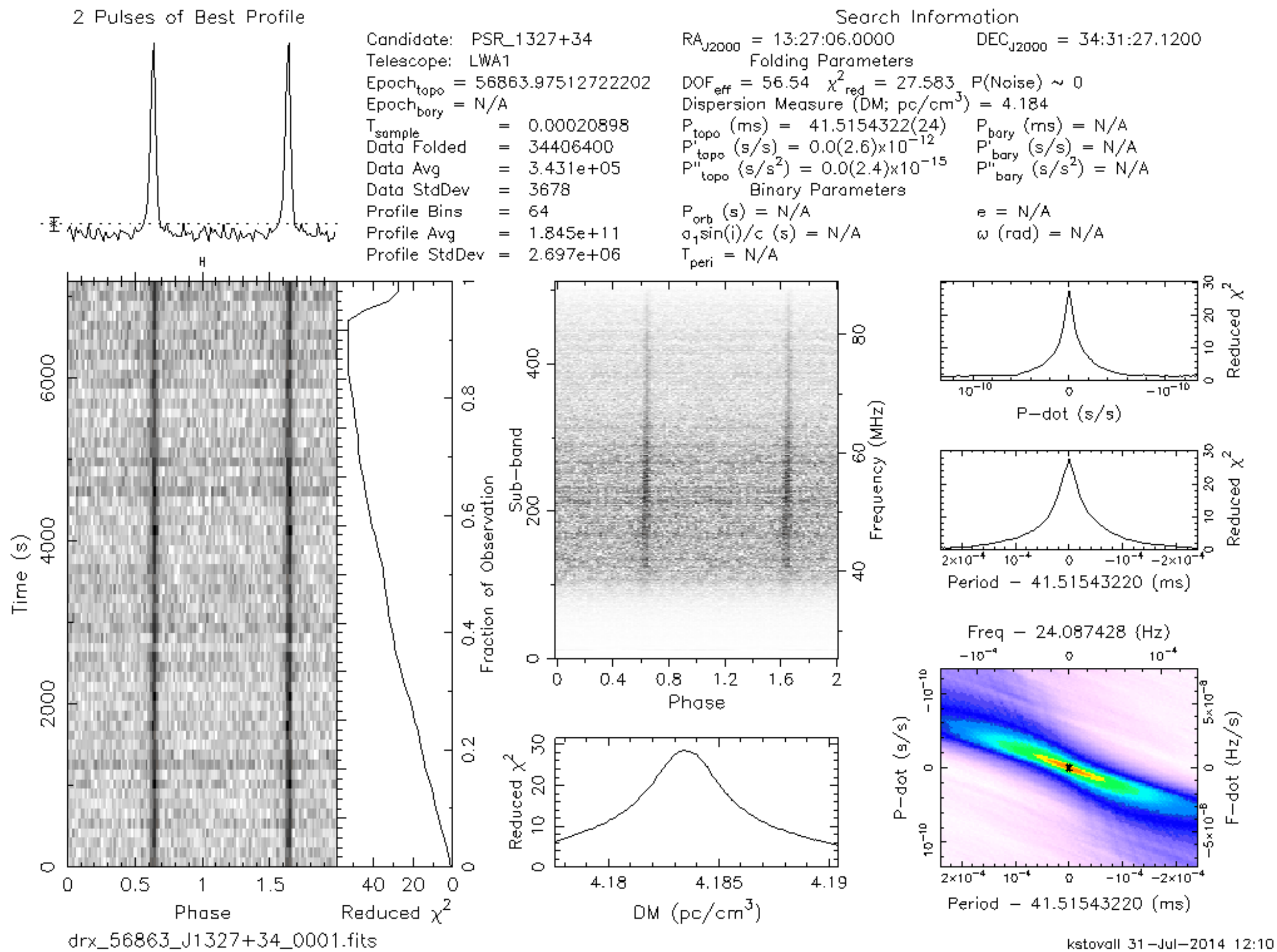
Emission from Hot Jupiters

- Low frequency:
  $eB / 2\pi m_e = 28$ MHz at 10 G
- Bright!
  ~100 mJy fluxes predicted
  (but less than confusion)
- High circular polarization:
  LWA1 is very good at this!
- Predictably time-variable:
  - pulsar-like emission
  - secondary eclipses
  - periastron passages of high-eccentricity HJs

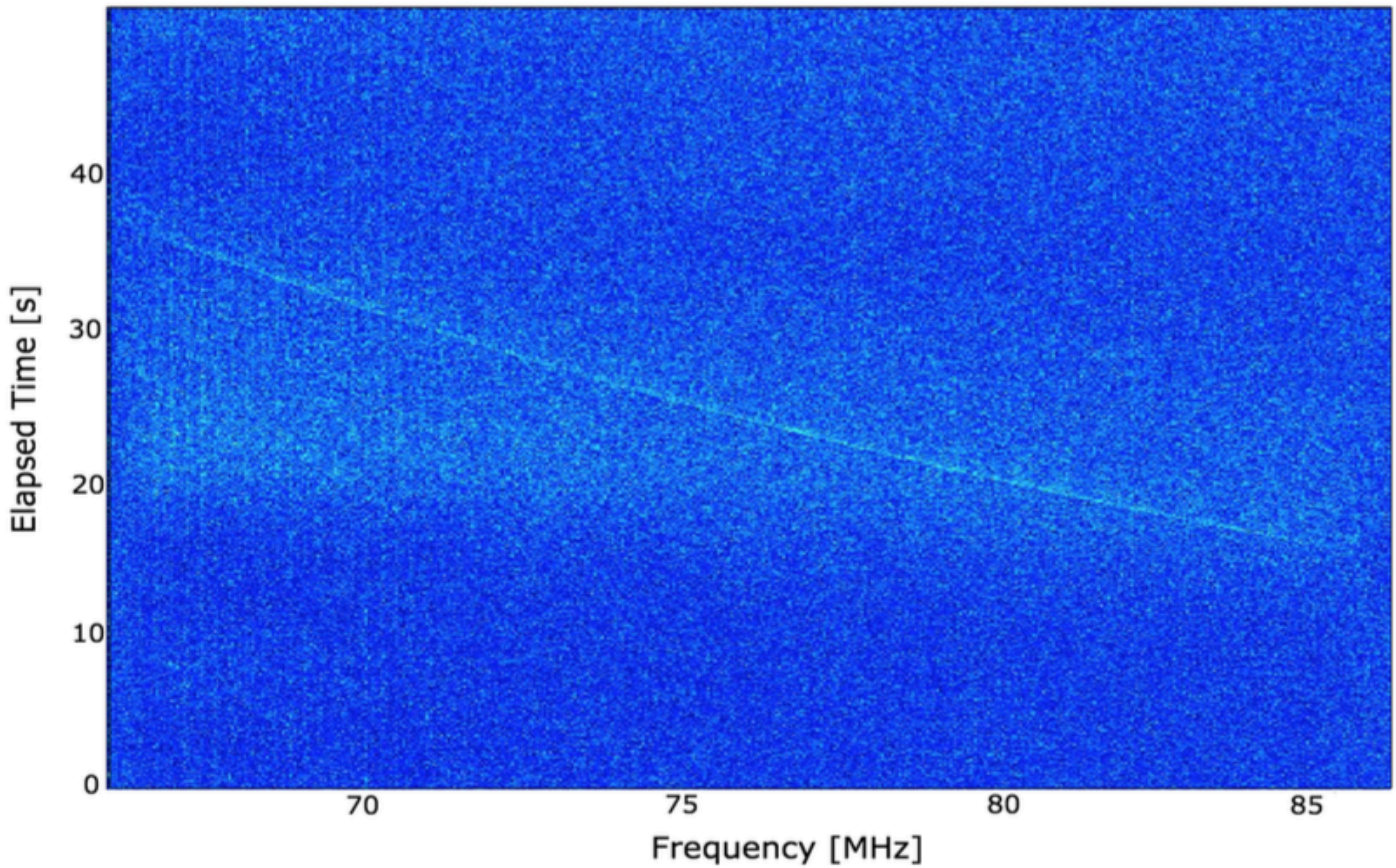


PASI image of a Jovian burst at 25.61 MHz

LWA1 Pulsar Detections



Dispersion of a Pulse

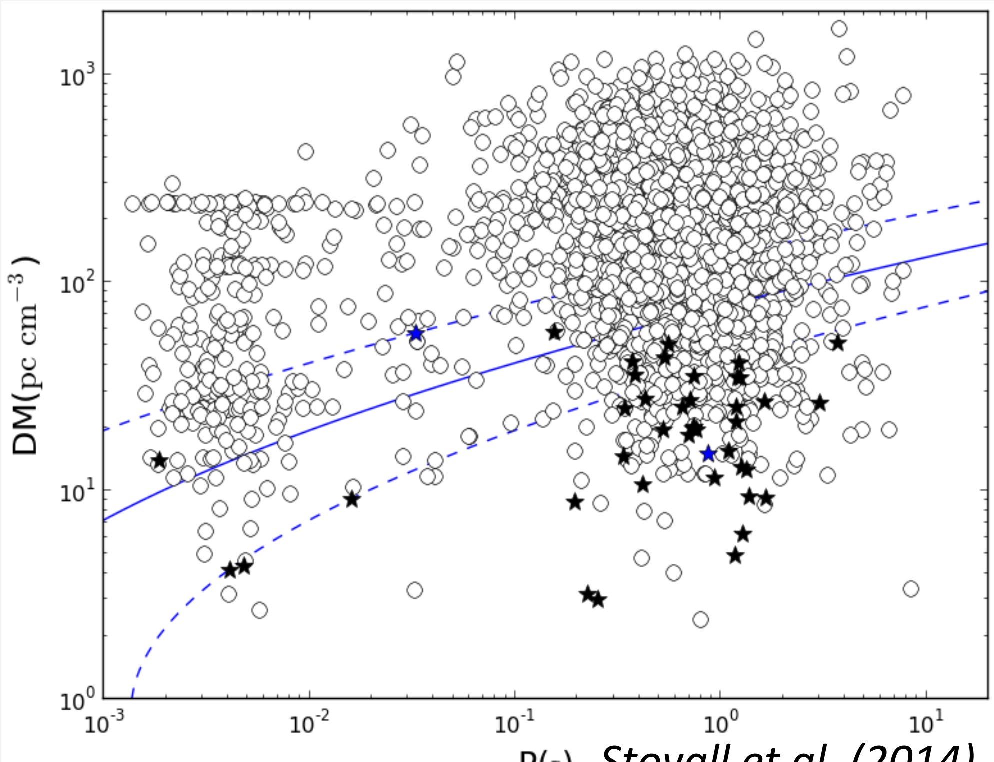


Eftekhari et al. (2016)

LWA1 Pulsar Detections

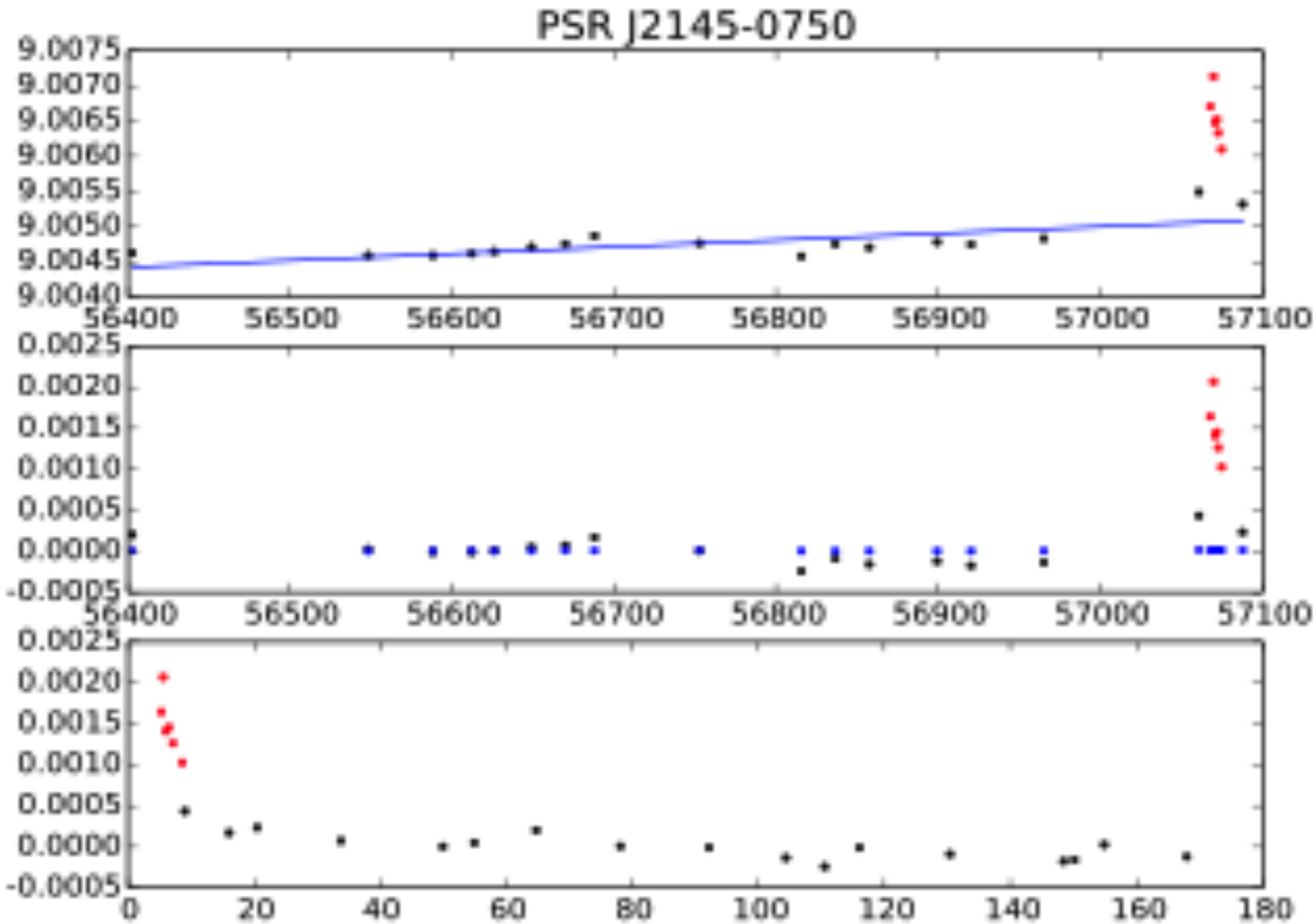
J0030+0451	B1133+16
B0031-07	B1237+25
J0034-0534	J1327+34
B0138+59	B1508+55
J0203+70	B1540-06
B0320+39	B1541+09
B0329+54	B1604-00
B0355+54	B1612+07
B0450+55	B1642-03
B0525+21	B1706-16
B0531+21*	B1749-28
B0628-28	B1822-09
B0655+64	B1839+56
B0809+74	B1842+14
B0818-13	B1919+21
B0823+26	B1929+10
B0834+06	B2020+28
B0919+06	B2110+27
B0943+10	J2145-0750
B0950+08	B2217+47
B1112+50	J2324-05

- 60 Pulsars detected (58 through pulsations, 2 through single pulses)
- 3 MSPs detected
- Periods from 1.9ms to 3.7s

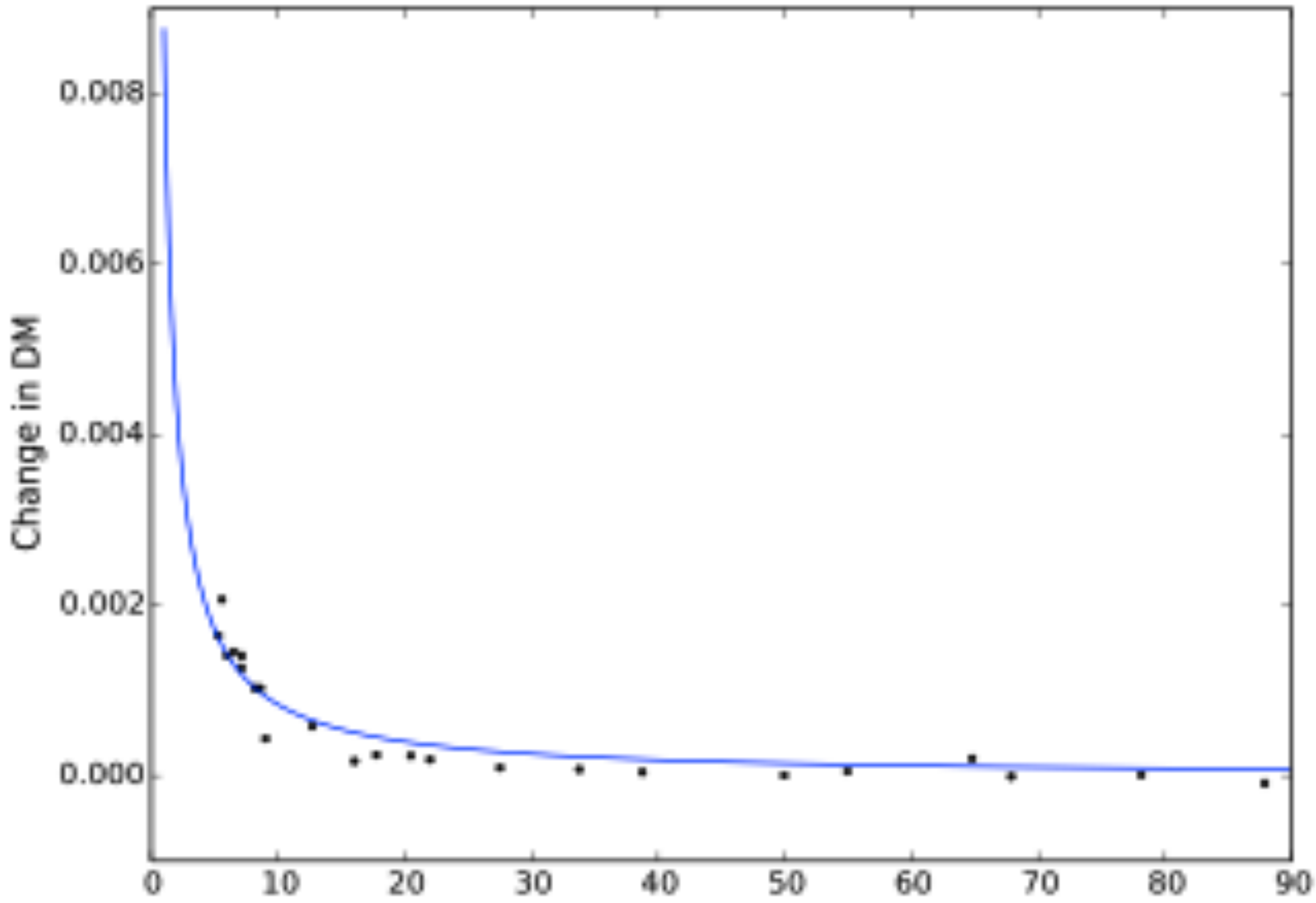


Stovall et al. (2014)

DM Variations



Solar System Electron Density



Rotation Measure Fitting

PSR B0950+08

$RM_{Meas} = 2.36(4)$

$RM_{ion} = 1.2(1)$

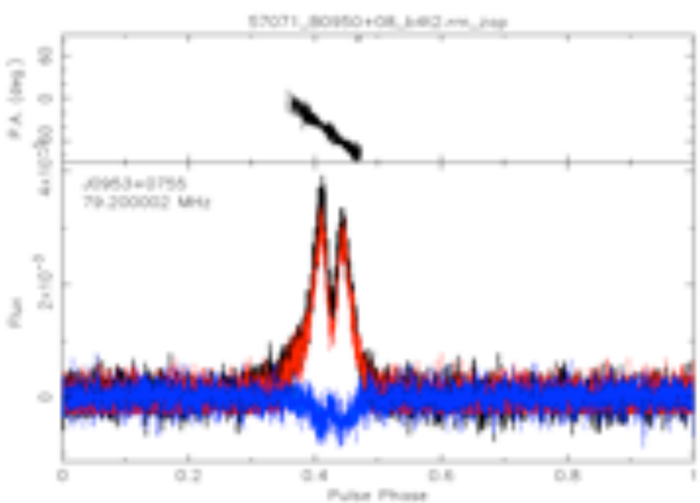
$RM_{corr} = 1.2(2)$

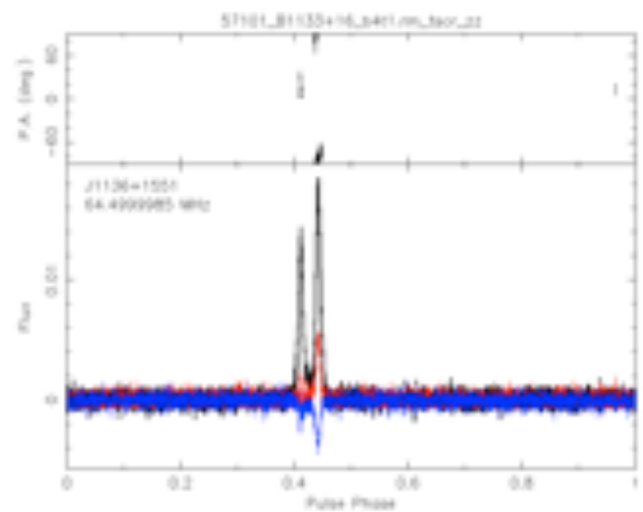
PSR B1133+16

$RM_{Meas} = 4.61(1)$

$RM_{ion} = 0.84(4)$

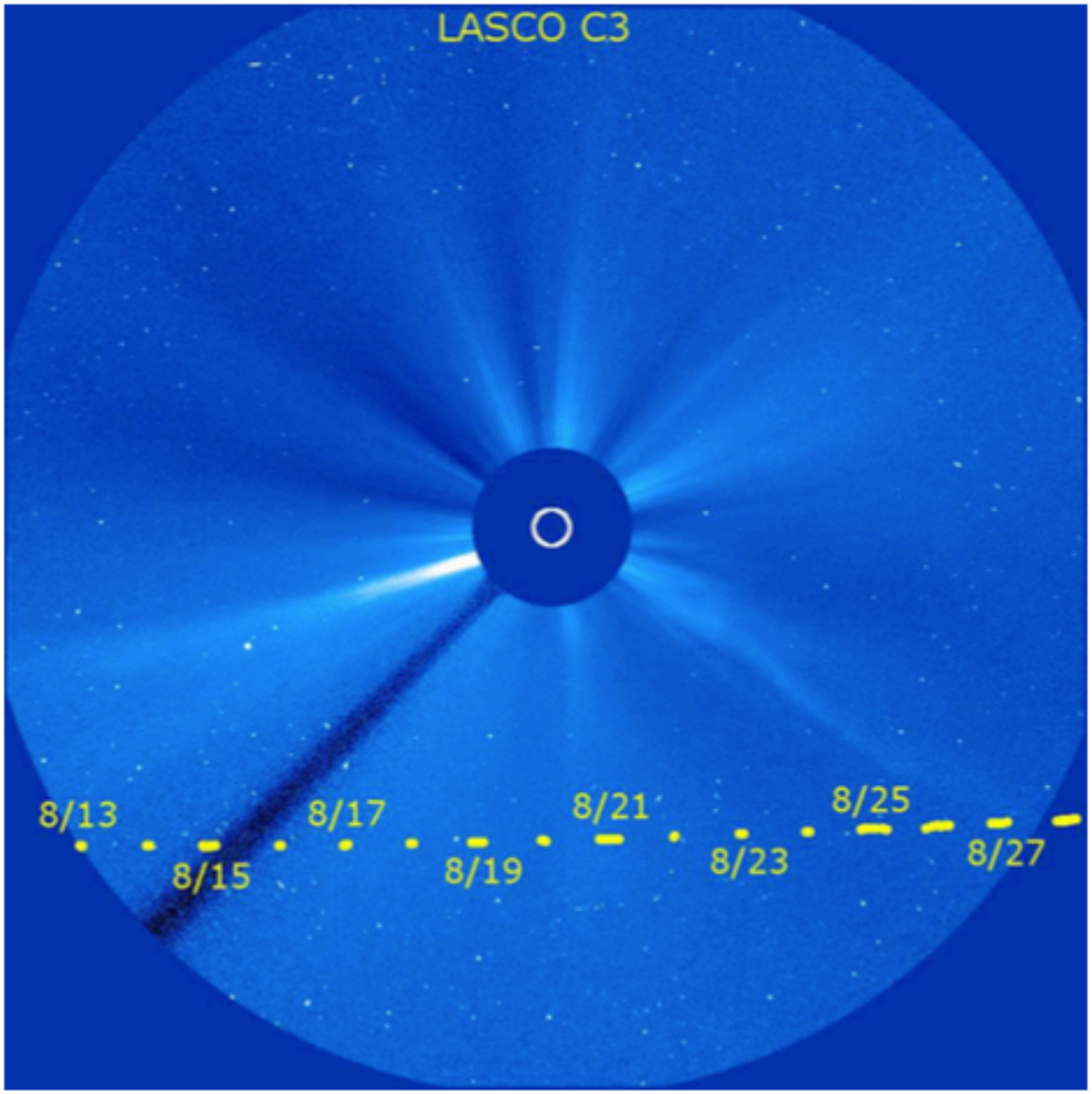
$RM_{corr} = 3.77(5)$





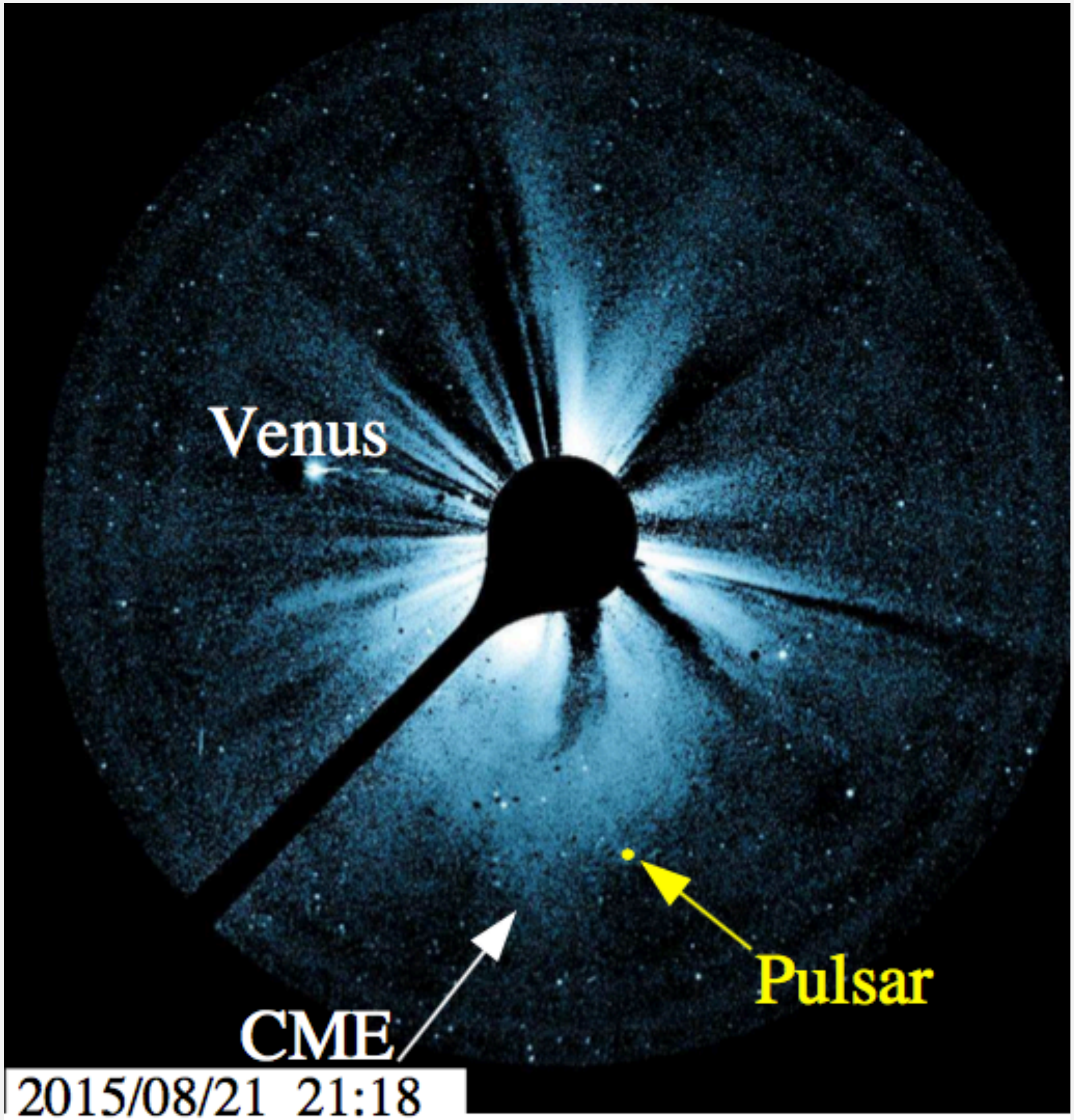
Coronal Mass Ejection

Catching a Coronal Mass Ejection

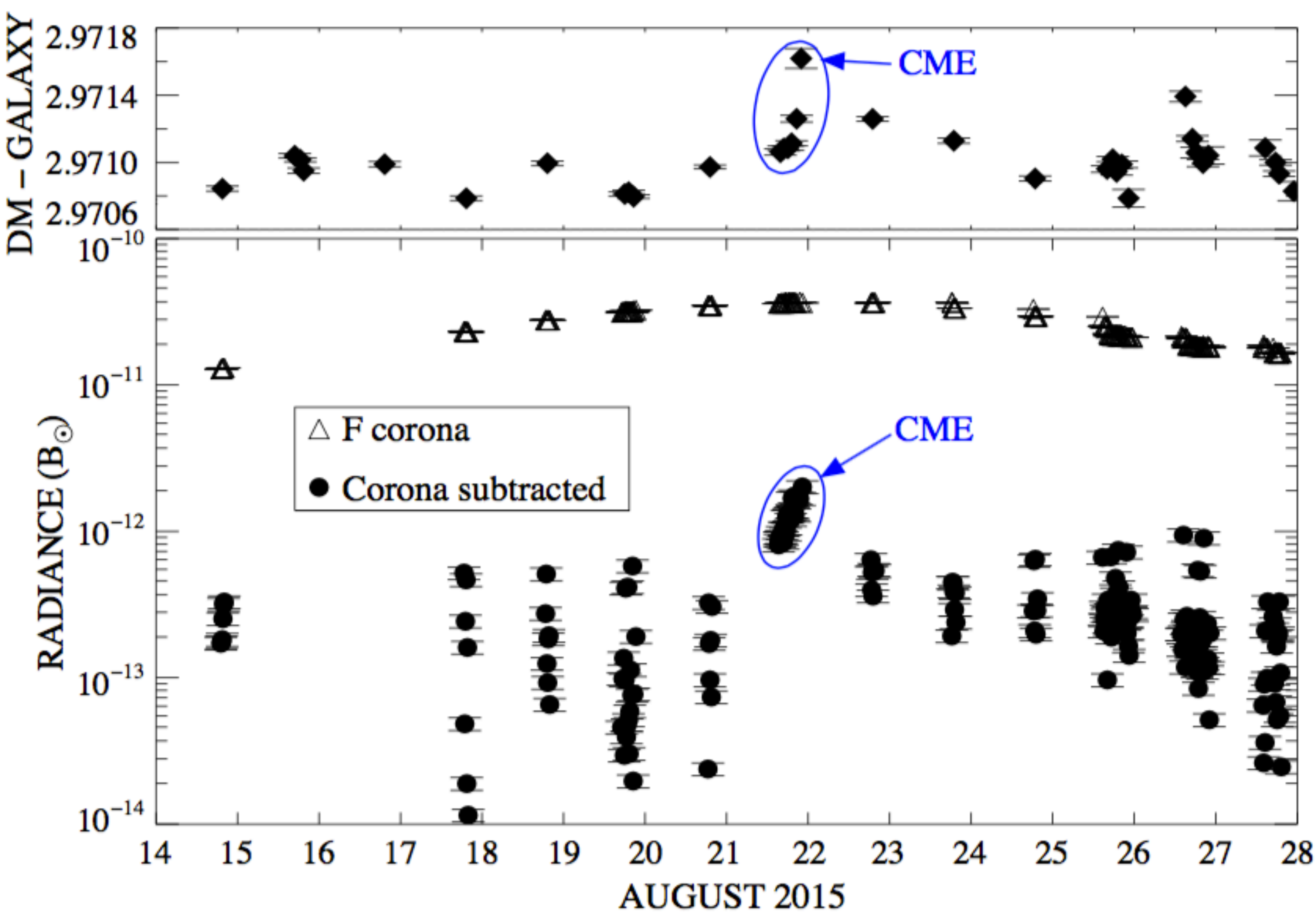


Howard et al 2016

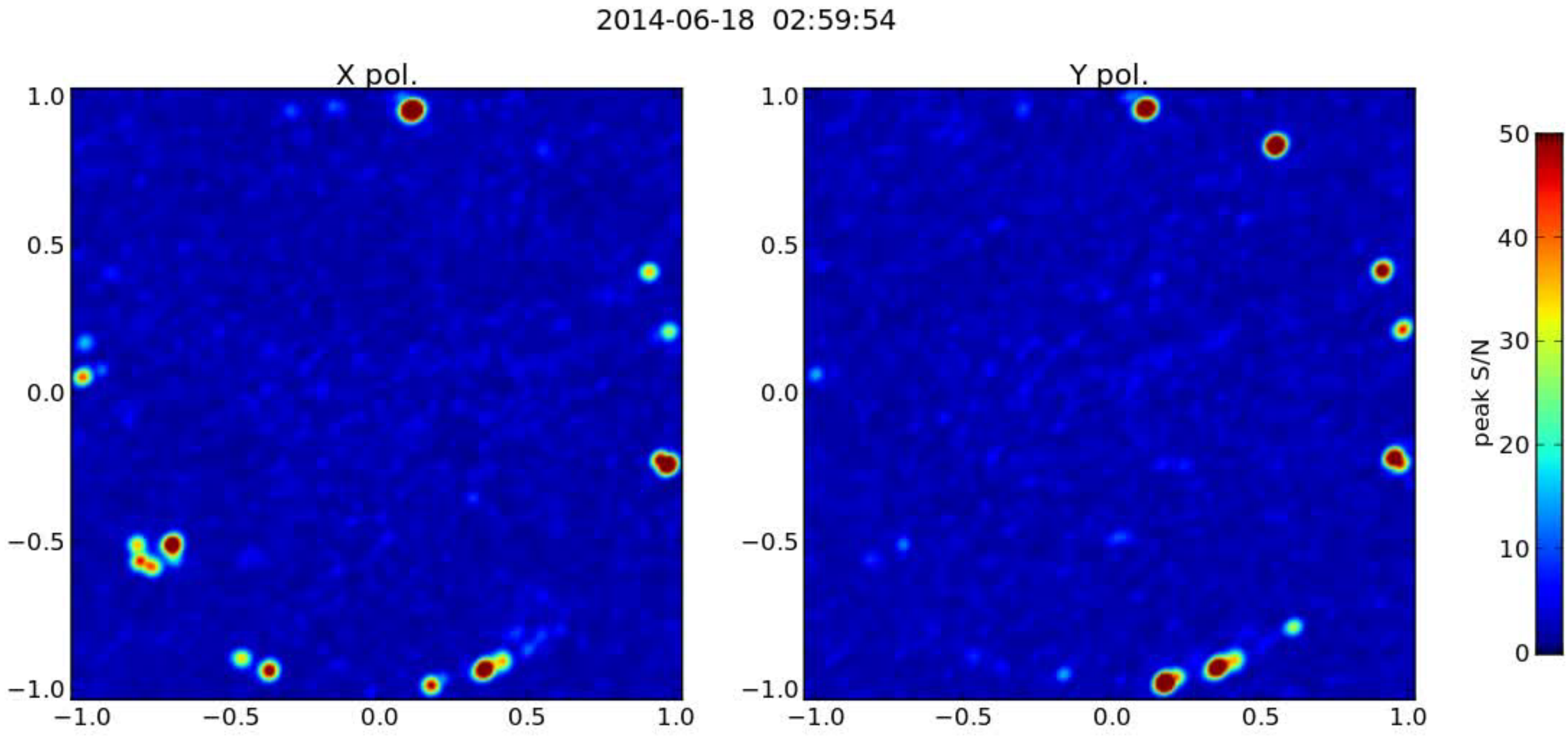
Catching a Coronal Mass Ejection



Catching a Coronal Mass Ejection

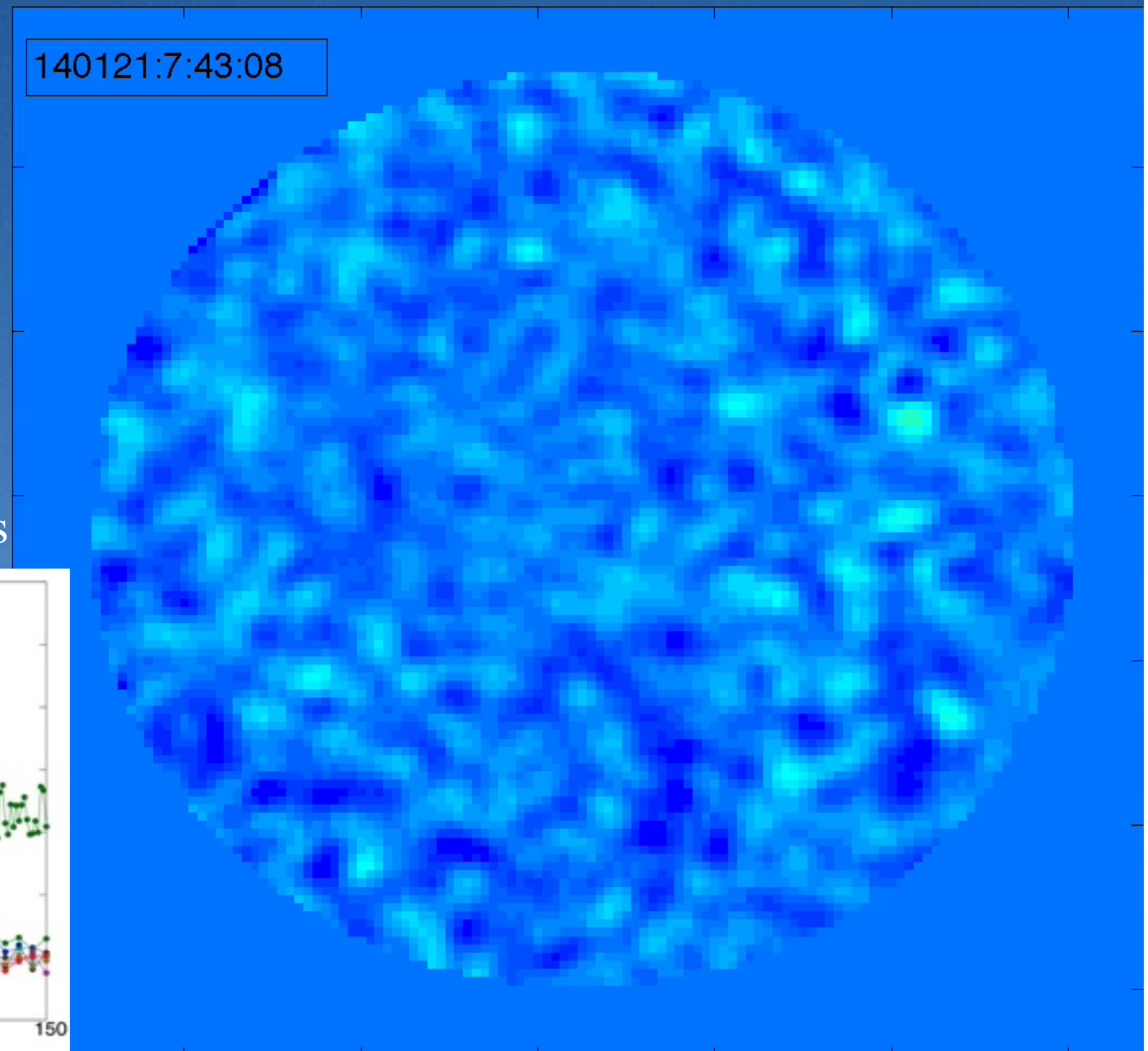


Meteors – by reflection

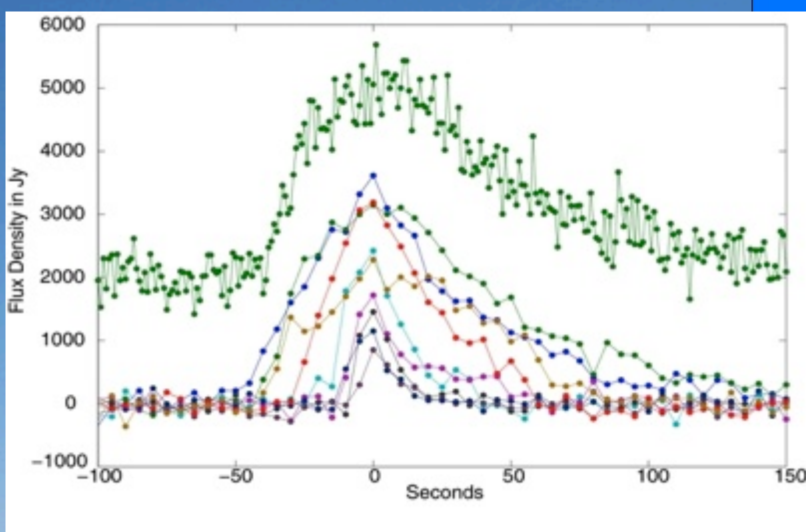


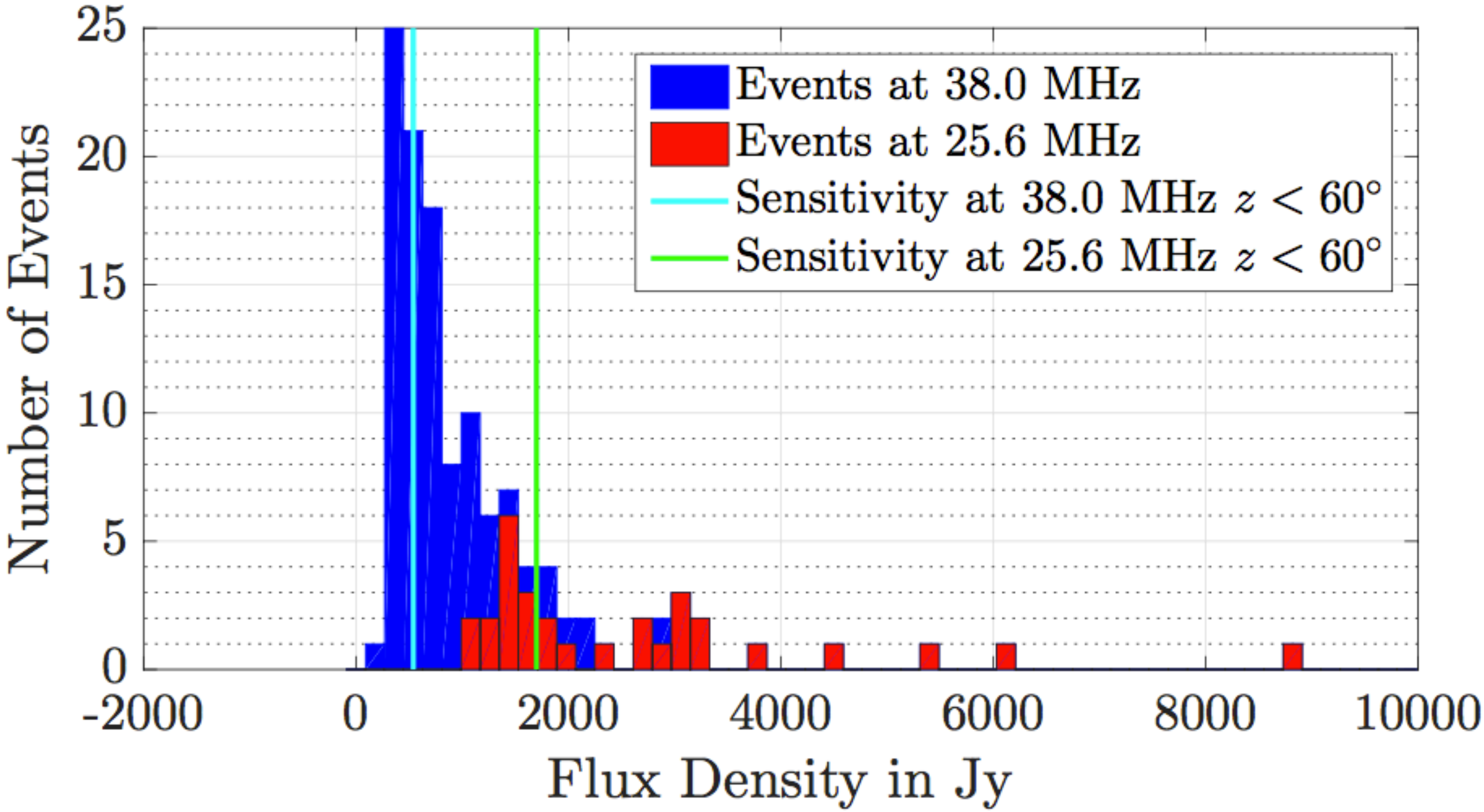
Great Balls of Fire!

Obenberger et al. 2014, 2016

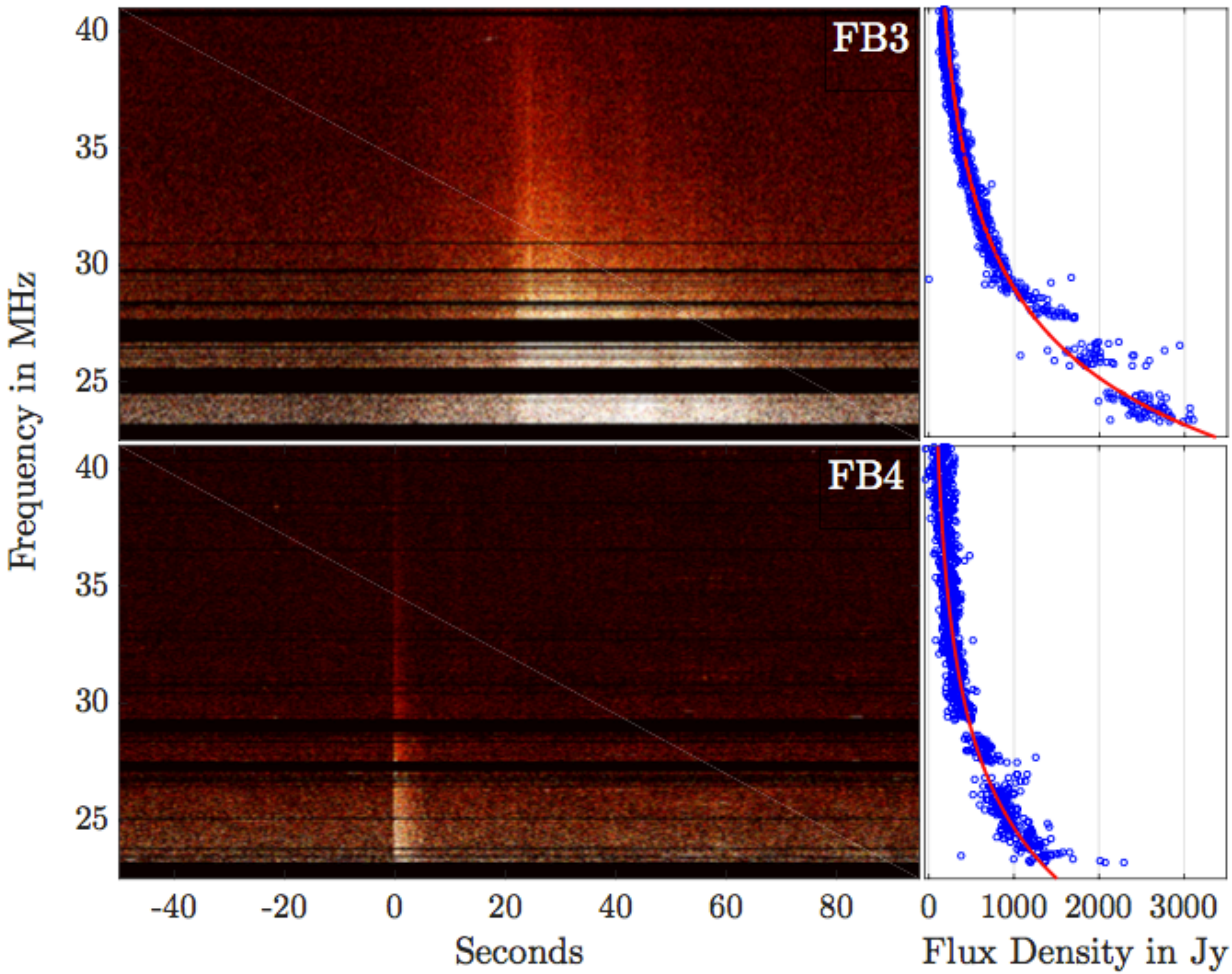


Light curves of the brightest transients





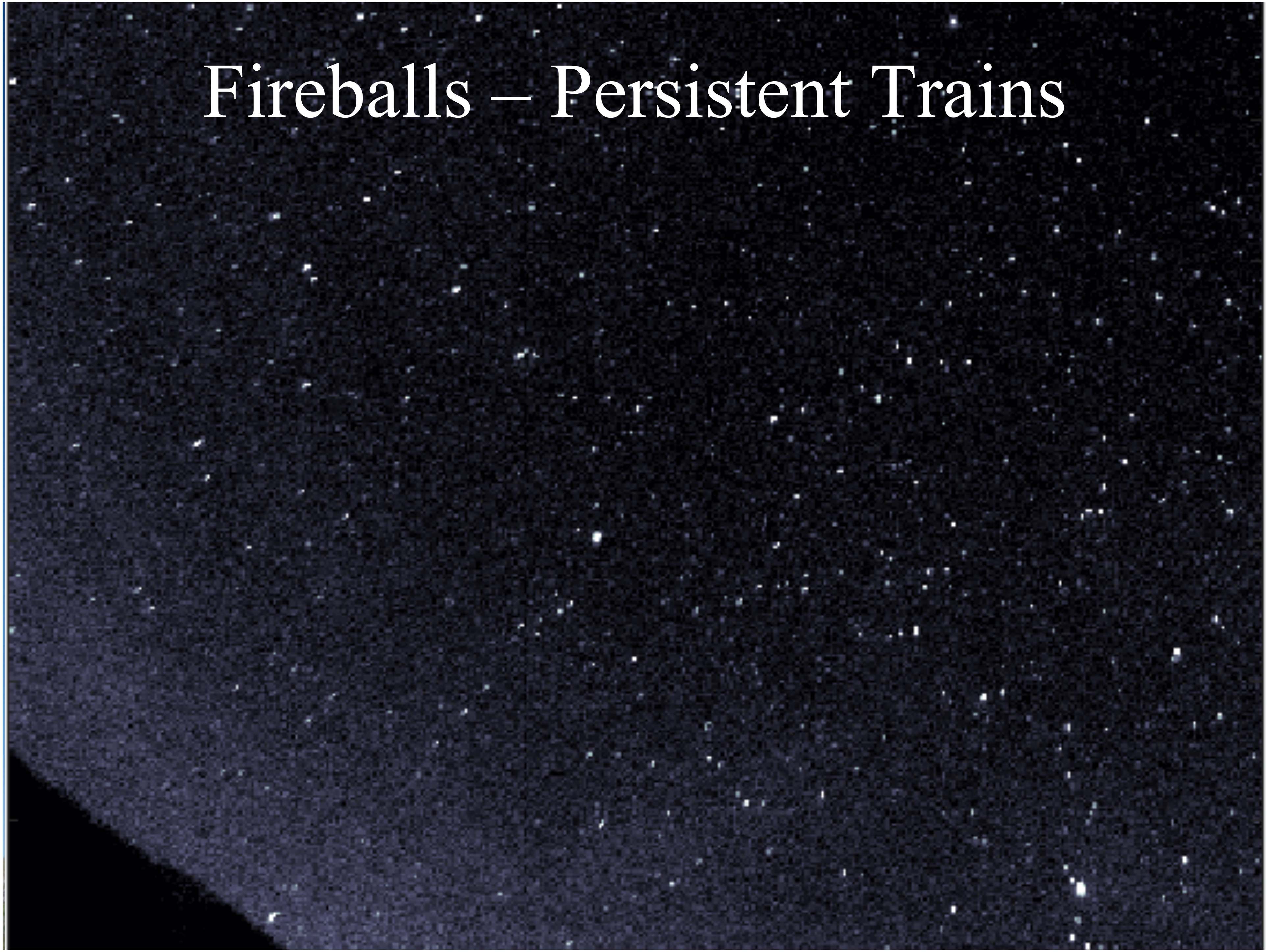
Obenberger et al 2016

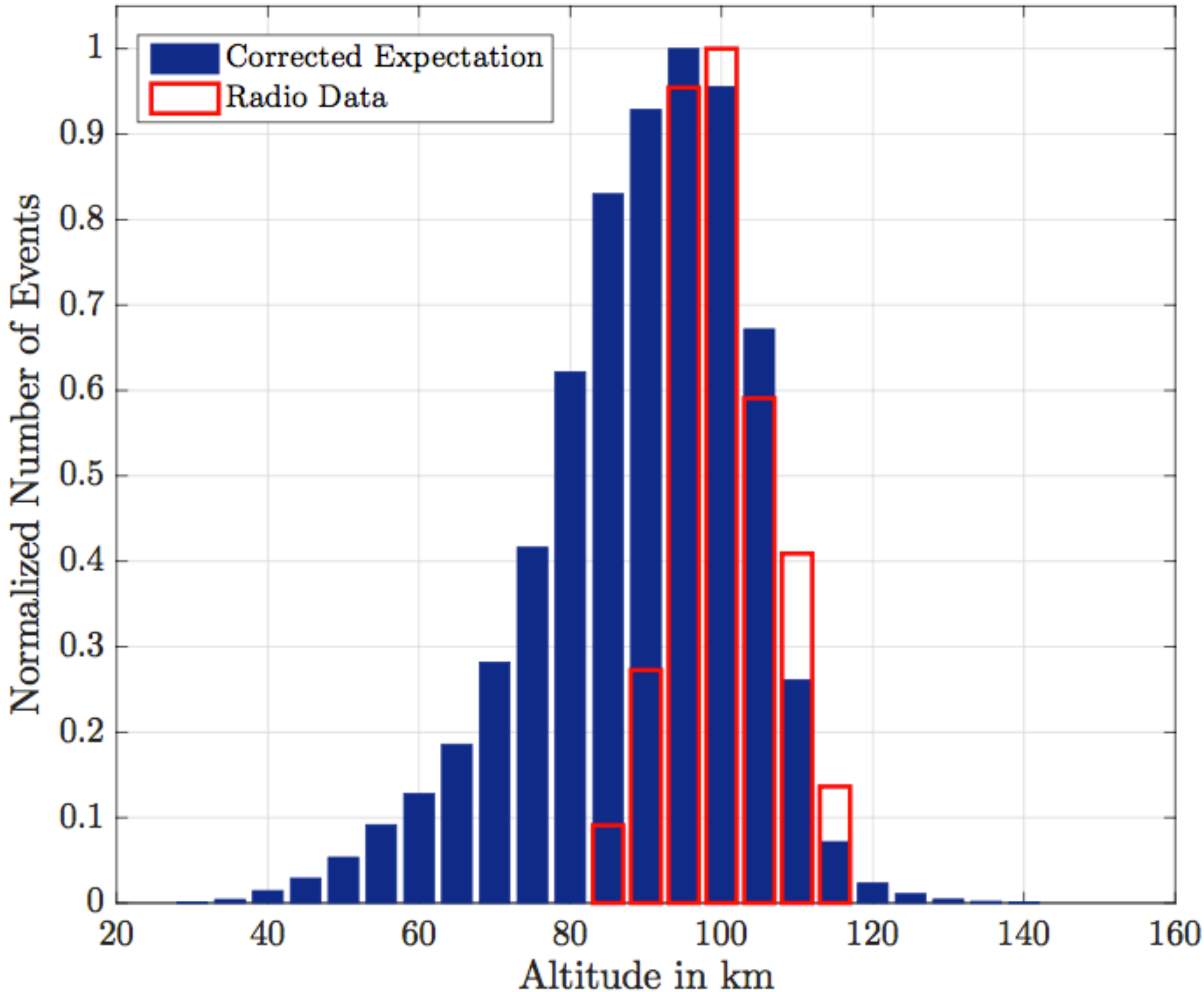


FB3
FB4
Frequency in MHz
40
35
30
25
-40
-20
0
20
40
60
80
Seconds
0
1000
2000
3000
Flux Density in Jy

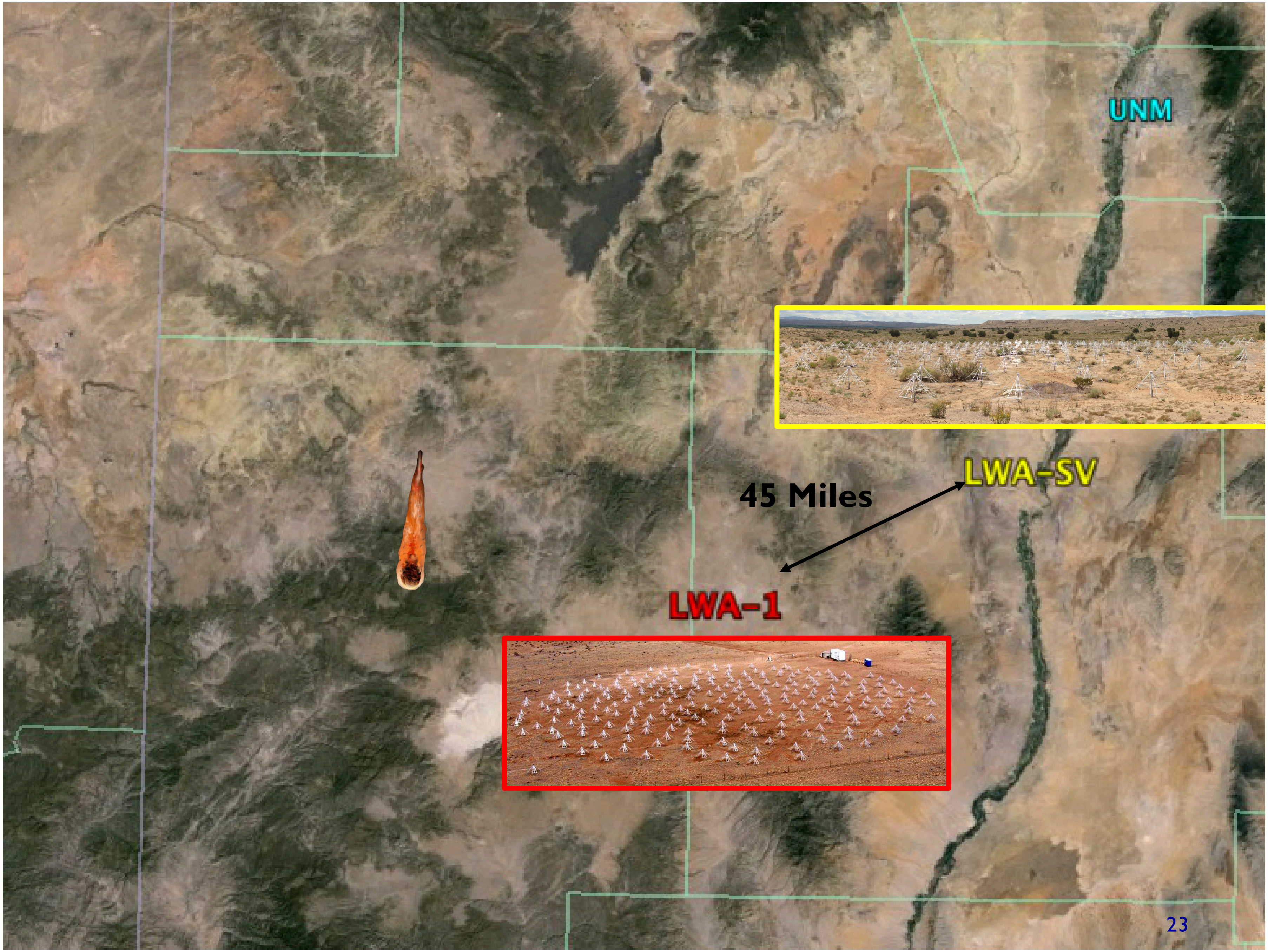
Fireballs – Persistent Trains

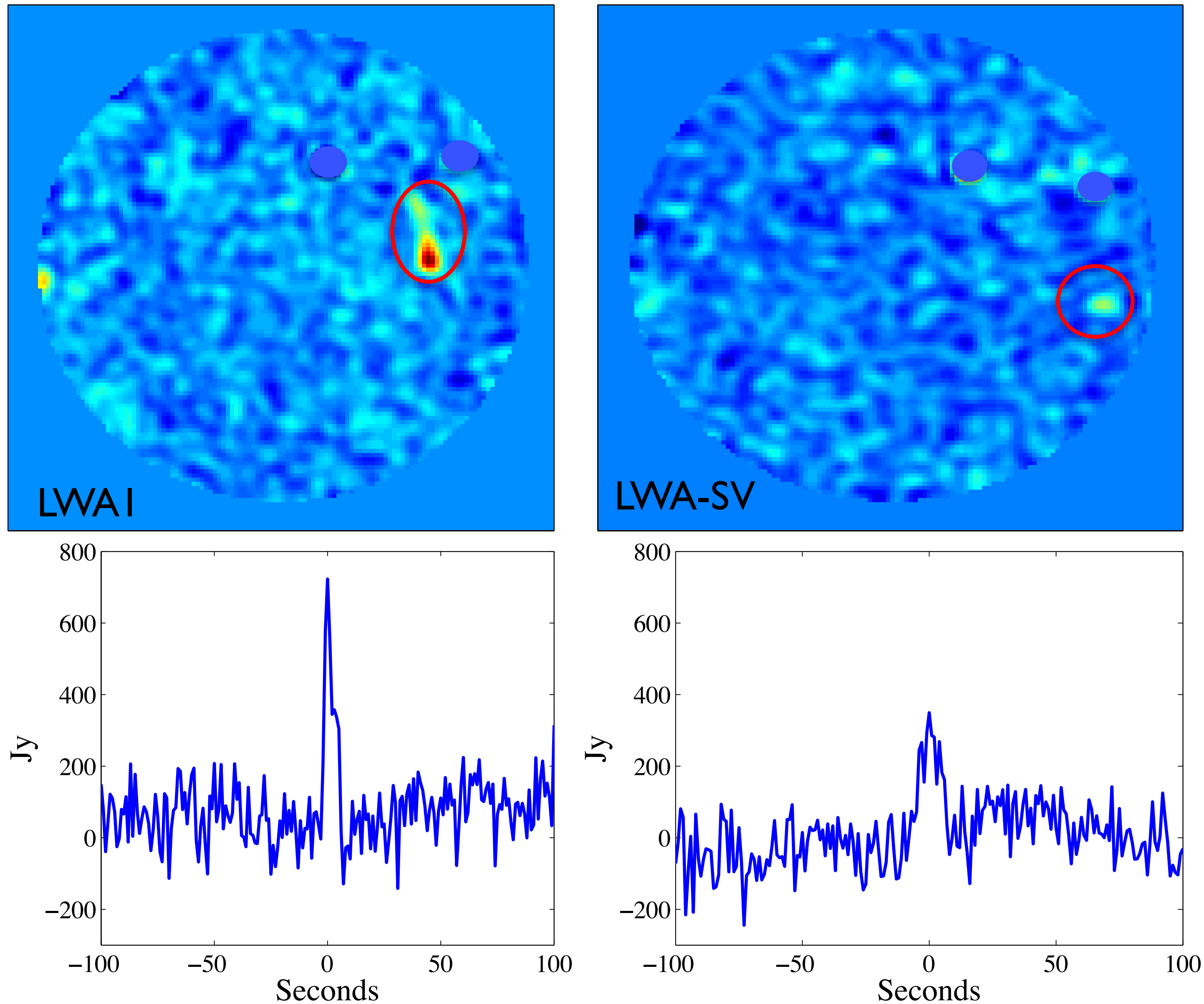
Fireballs – Persistent Trains





Corrected Expectation
Radio Data
Normalized Number of Events
Altitude in km
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
20
40
60
80
100
120
140
160

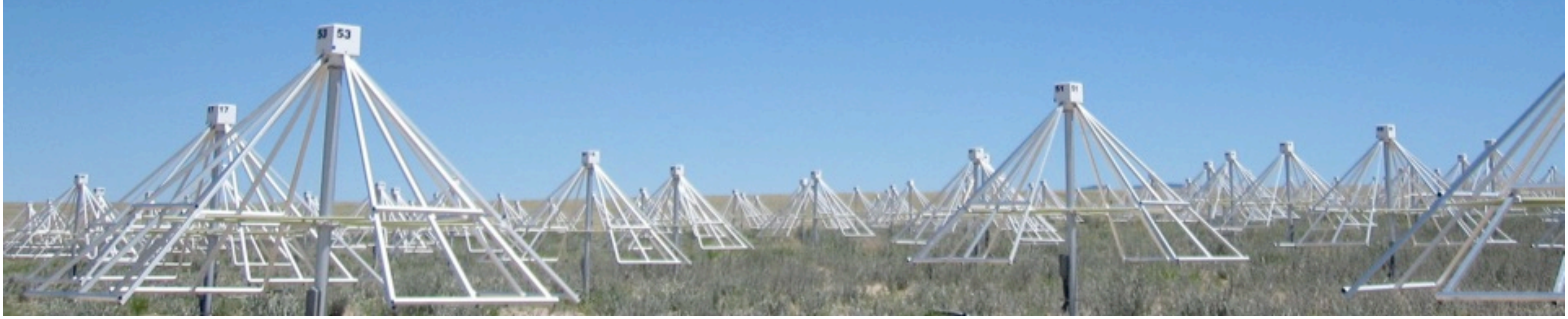

UNM
LWA-SV
45 Miles
LWA-1


LWA1
LWA-SV
800
600
400
200
0
−200
Jy
−100
−50
0
50
100
Seconds

Expanded LWA - Demonstration

New 4 band feeds (MJP)
4 meter band: 50-86 MHz

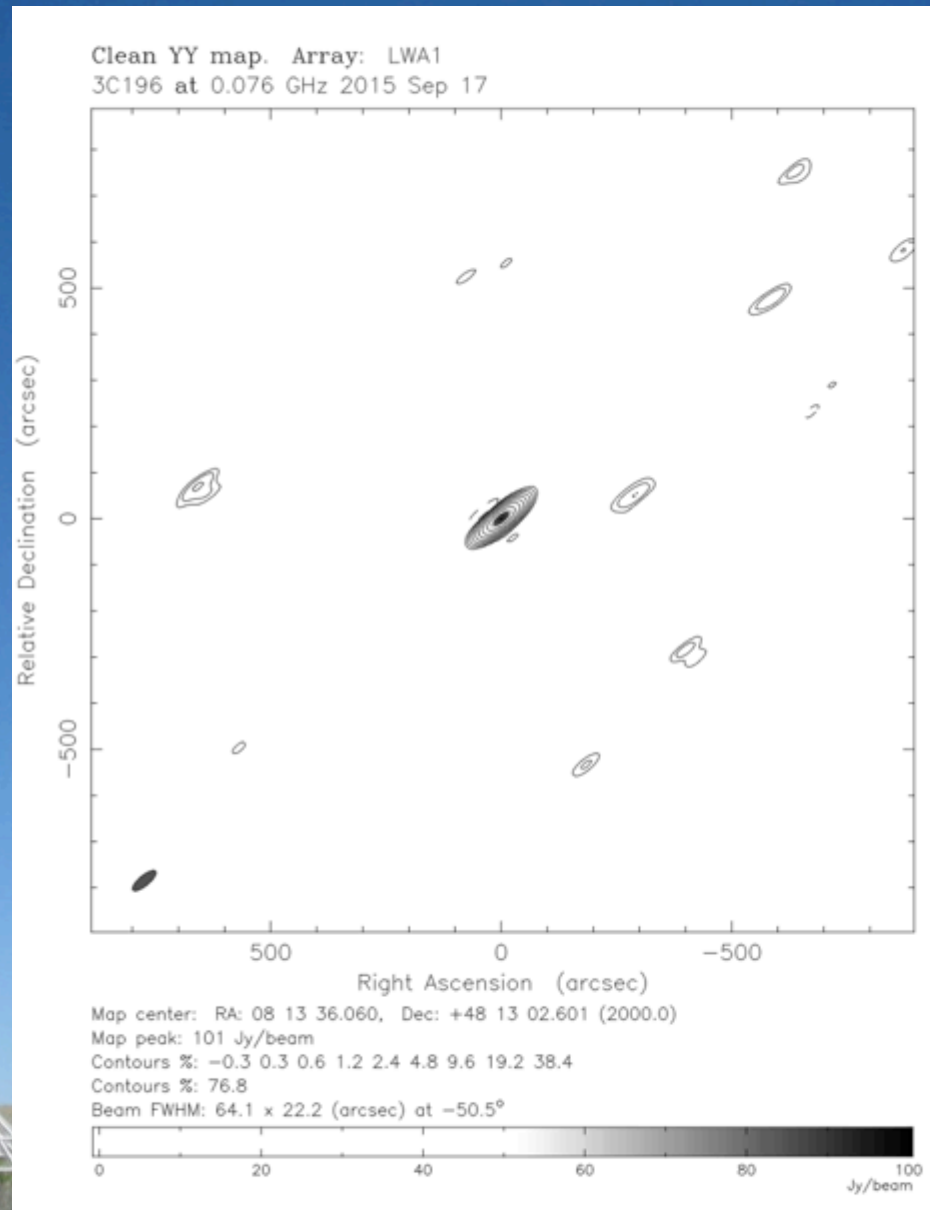
9/17/2015: 3C196
6 VLA + LWA1
35 minutes
72 – 80 MHz
Correlated using the
LWA Software Library



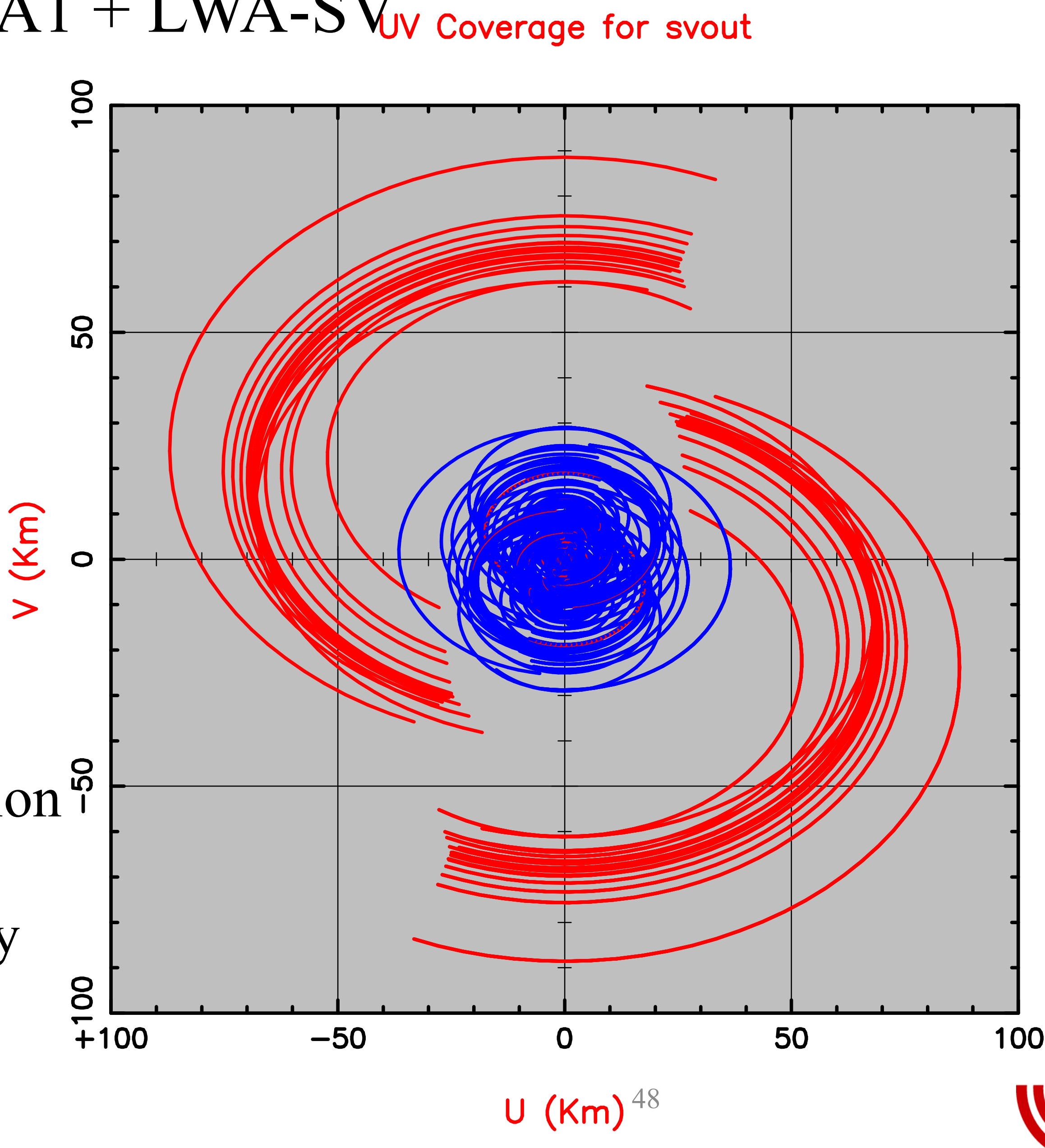
ELWA - Demonstration

3C196
Peak ~ 100 Jy
Noise ~ 200 mJy
SEFD ~ 8000 Jy LWA1
SEFD ~ 25000 Jy ea14, ea10

Resolution increased by factor of 250!



16 VLA + LWA1 + LWA-SV

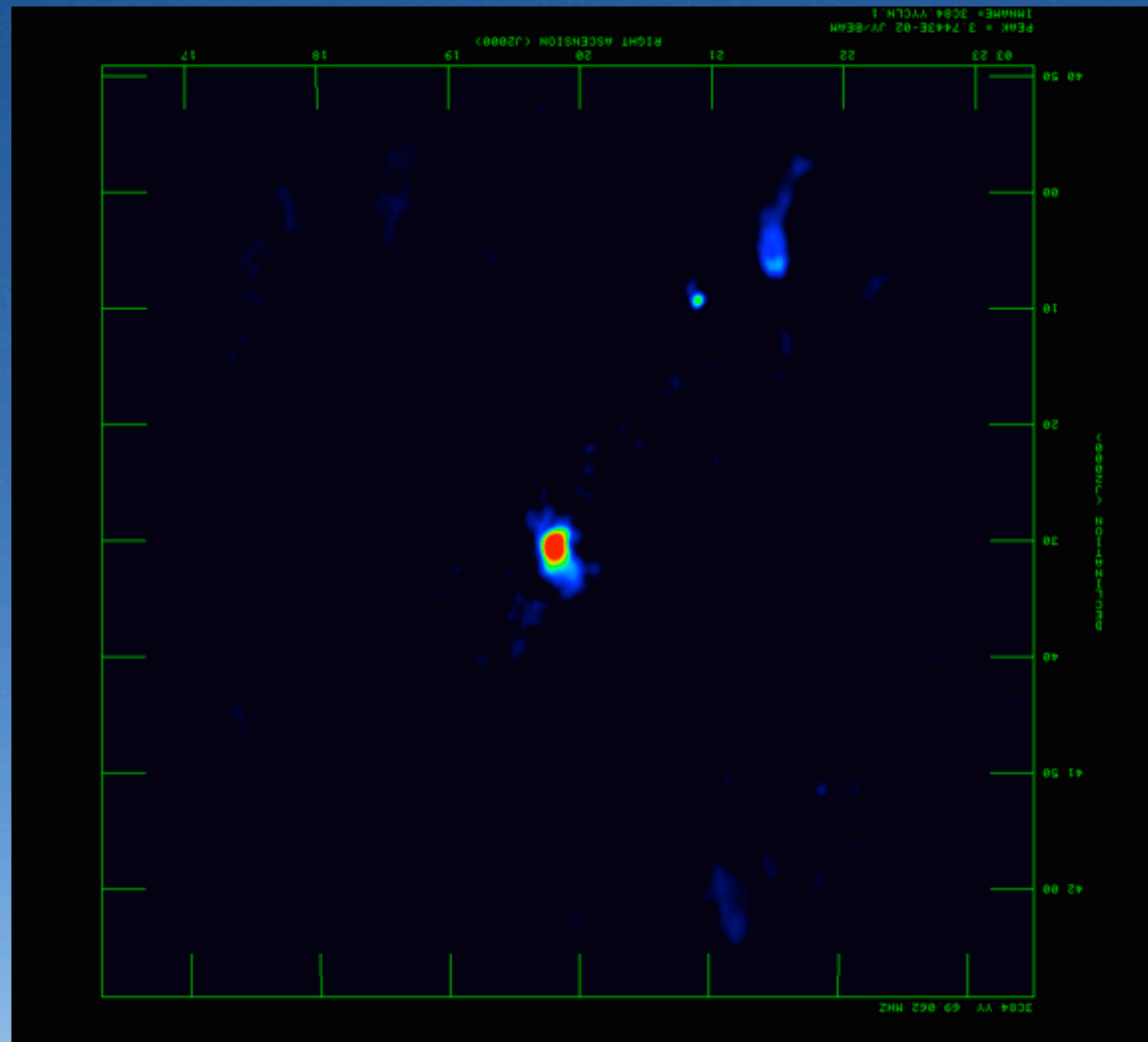


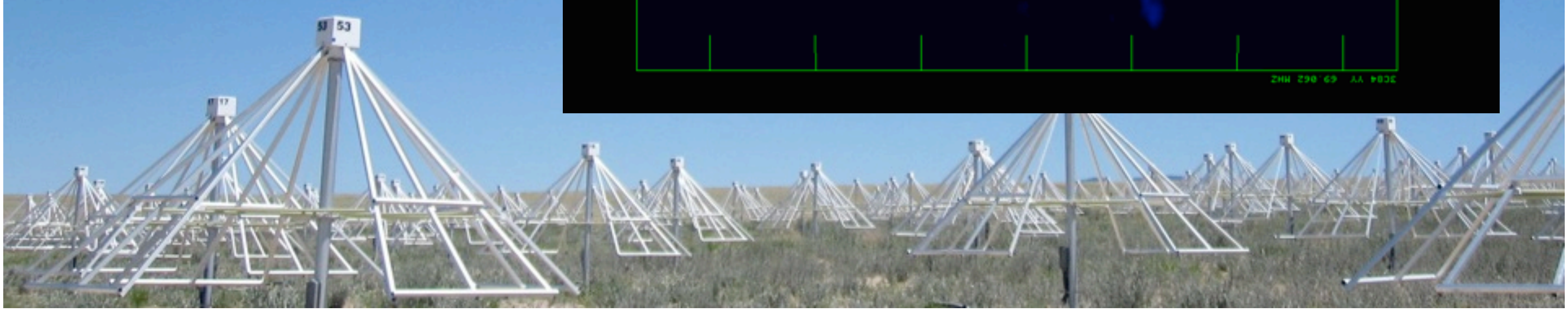
~10 arcsec resolution at 74 MHz

~20 mJy sensitivity

ELWA - Demonstration

3C84
Dec 3, 2016
LWA1 + 13 VLA

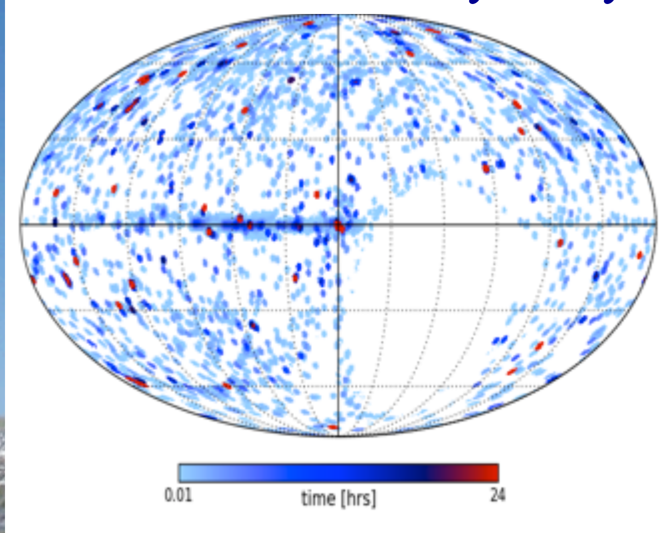




ngVLA Option: Commensal Low Frequency Science

LWA: all sky plus beams

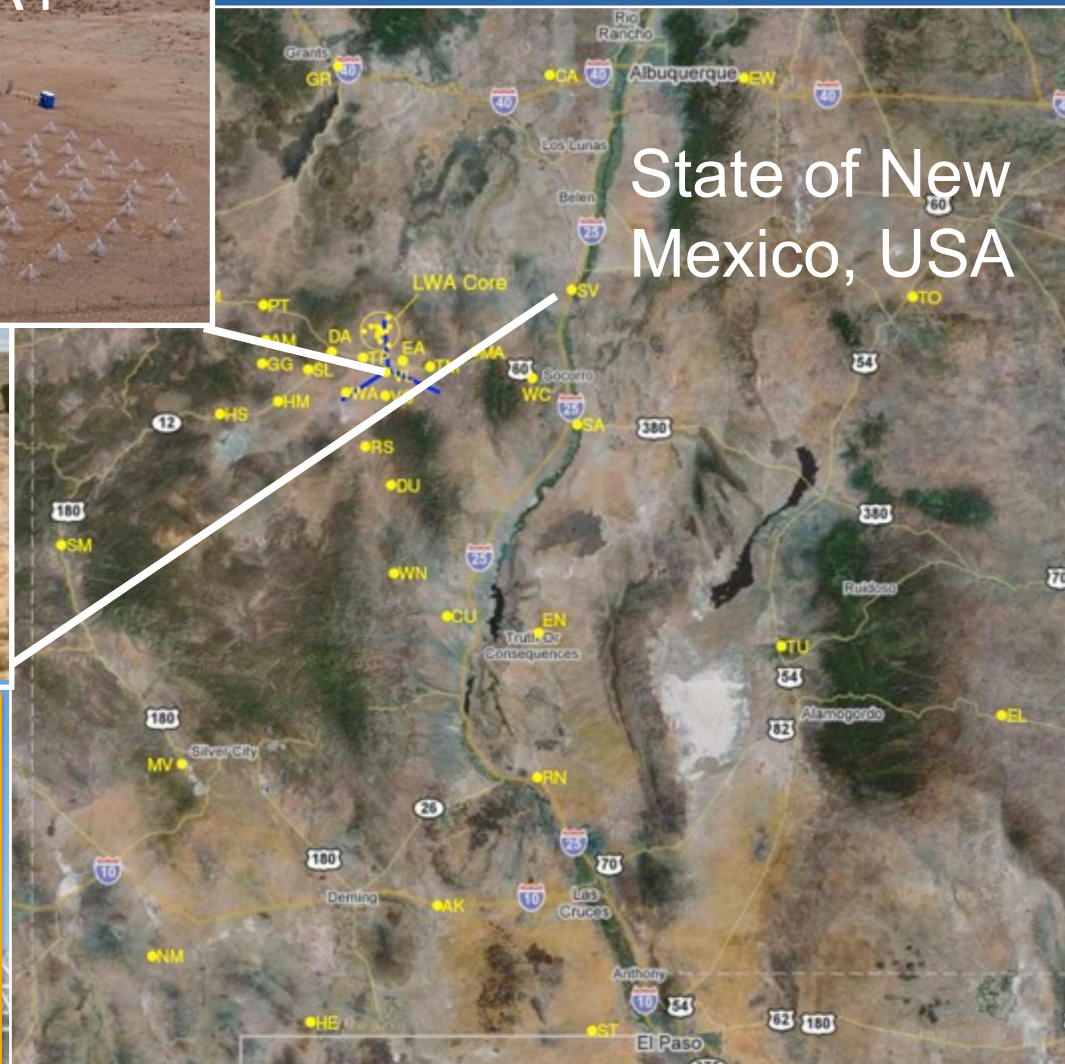
VLITE: >50% of sky in 1 year



- Current infrastructure:
  - VLITE + LWA => Low Band Observatory (LOBO)
- Future: Leverage ngVLA infrastructure (land/fiber/power) for commensal low frequency capabilities (ngLOBO)
- 5 – 150 MHz: multi-beam dipole arrays alongside ngVLA long-baseline stations (e.g., LWA style).
- 150 – 800 MHz commensal prime focus feeds on ngVLA antennas (e.g., VLITE style)
- Science: efficiently exploring the entire low frequency Universe with (almost) “free photons” so transients, pulsars, space weather, exo-planets, …

LWA Future

- 10-88 MHz Aperture Synthesis Telescope
- 4 beams x 2 pol. x 2 tunings x 16 MHz
- 2 all-sky transient obs. modes



- Goal of 50 LWA stations, baselines up to 400 km for resolution 2” at 80 MHz with mJy sensitivity
- Cost is ~$1M/station

Summary

- LWA1 has demonstrated technical feasibility and scientific results
- Lots of exciting science at low frequencies. Progress requires:
  - High temporal, spectral, and spatial resolution
  - Sensitivity
  - Software development
- Current experiments are providing new hardware and software, and a better understanding of the sky at long wavelengths
- We have begun the next phase – interferometry with LWA and VLA stations
- What would you do with a Million Dollars?

LWA
Long Wavelength Array

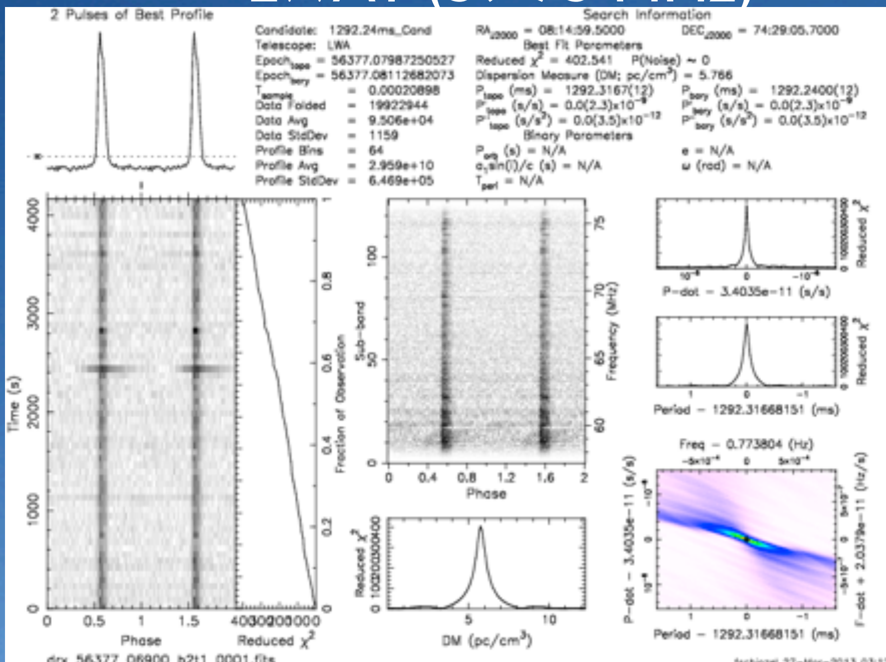
Extra Slides

LWA
Long Wavelength Array

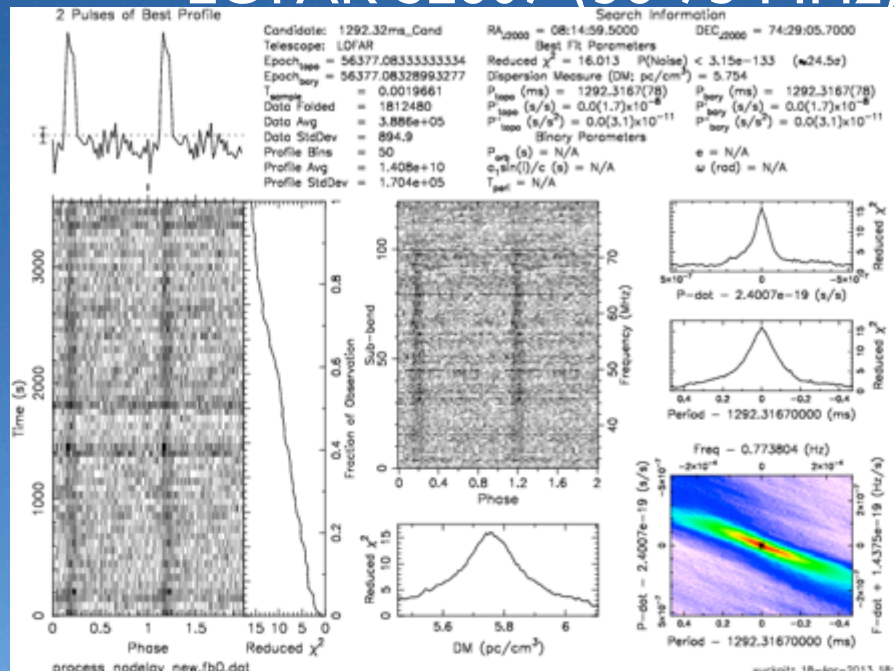
Using Pulsars to compare sensitivity

LWA1 Compared to LOFAR Int'l Station

LWA1 (59-75 MHz)



LOFAR SE607 (36-75 MHz)

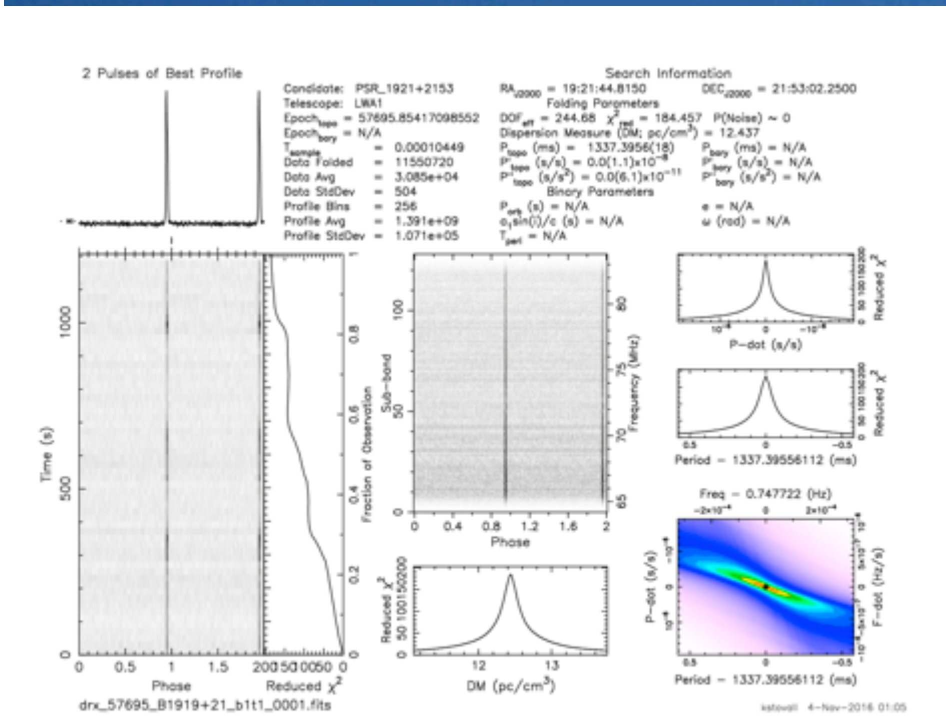


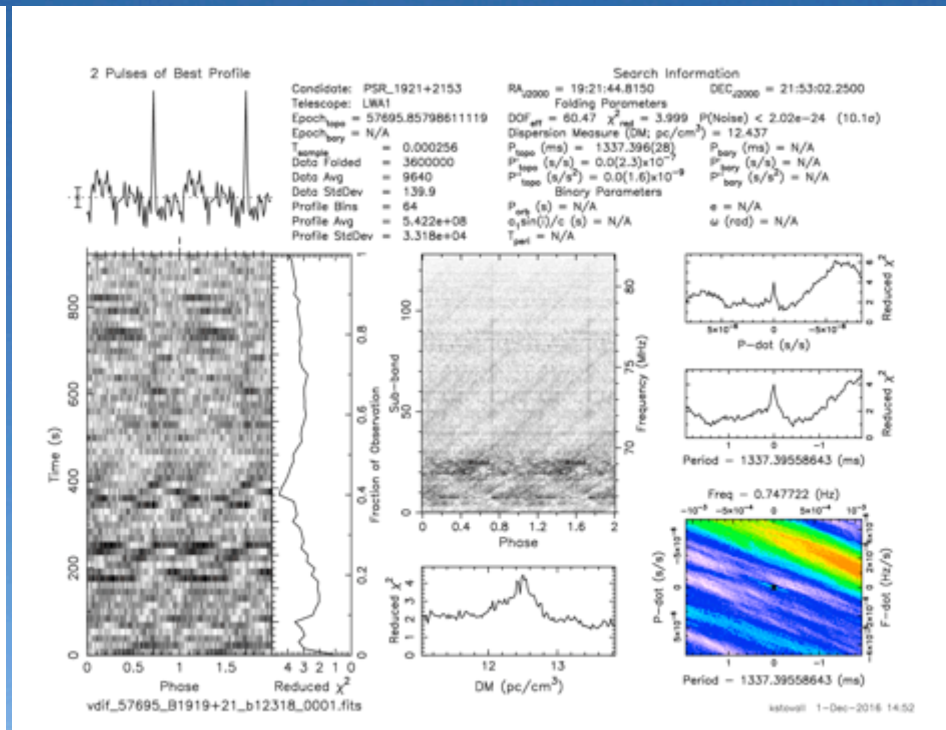
256 dipoles vs 96 dipoles

PSR B0809+74 (Wucknitz, Schinzel, McKay, Carozzi)

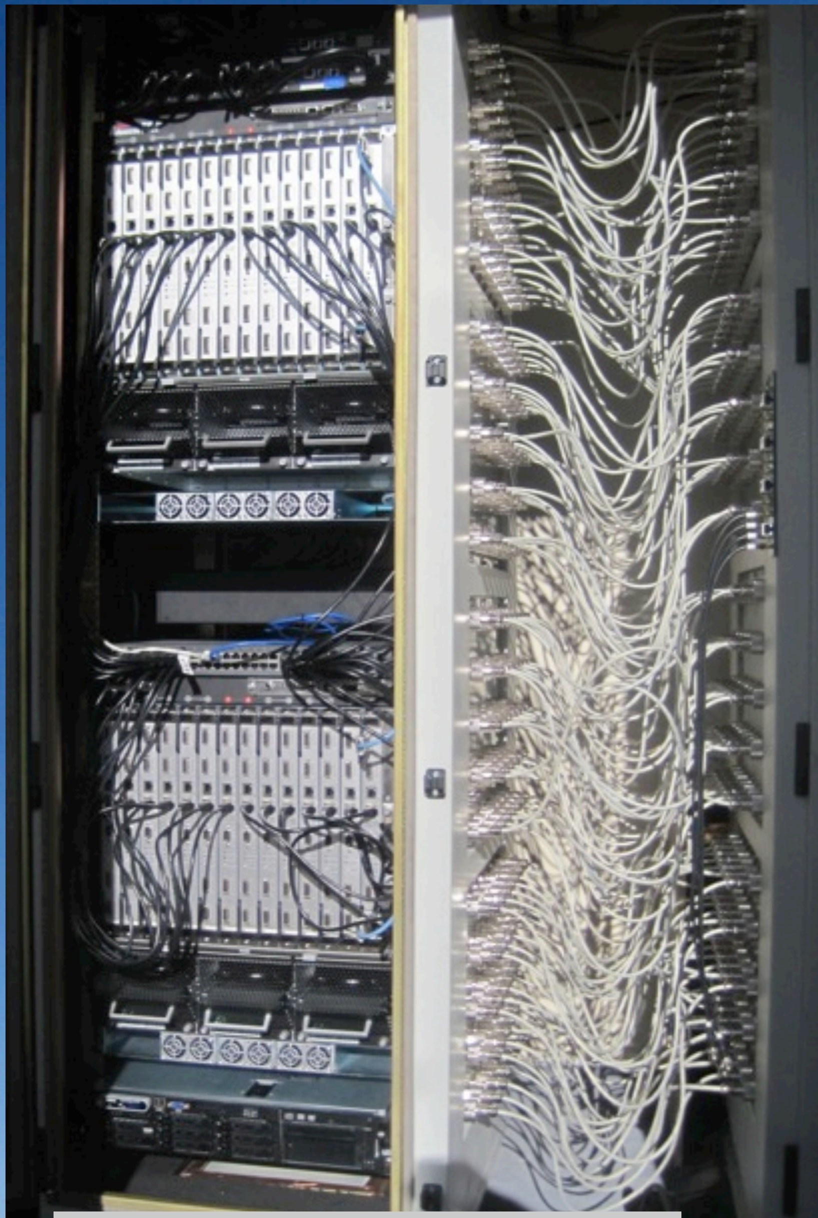
PSR B1919+21

- Test observation on Nov 03rd 2016, 20 min
- 12 antennas (A config.) + LWA1
- 16 MHz bandwidth/4 bit





LWA1 256 dipoles vs. VLA ant18 25m dish with MJP



Digital Processor (DP)

Analog Signal Processor (ASP)

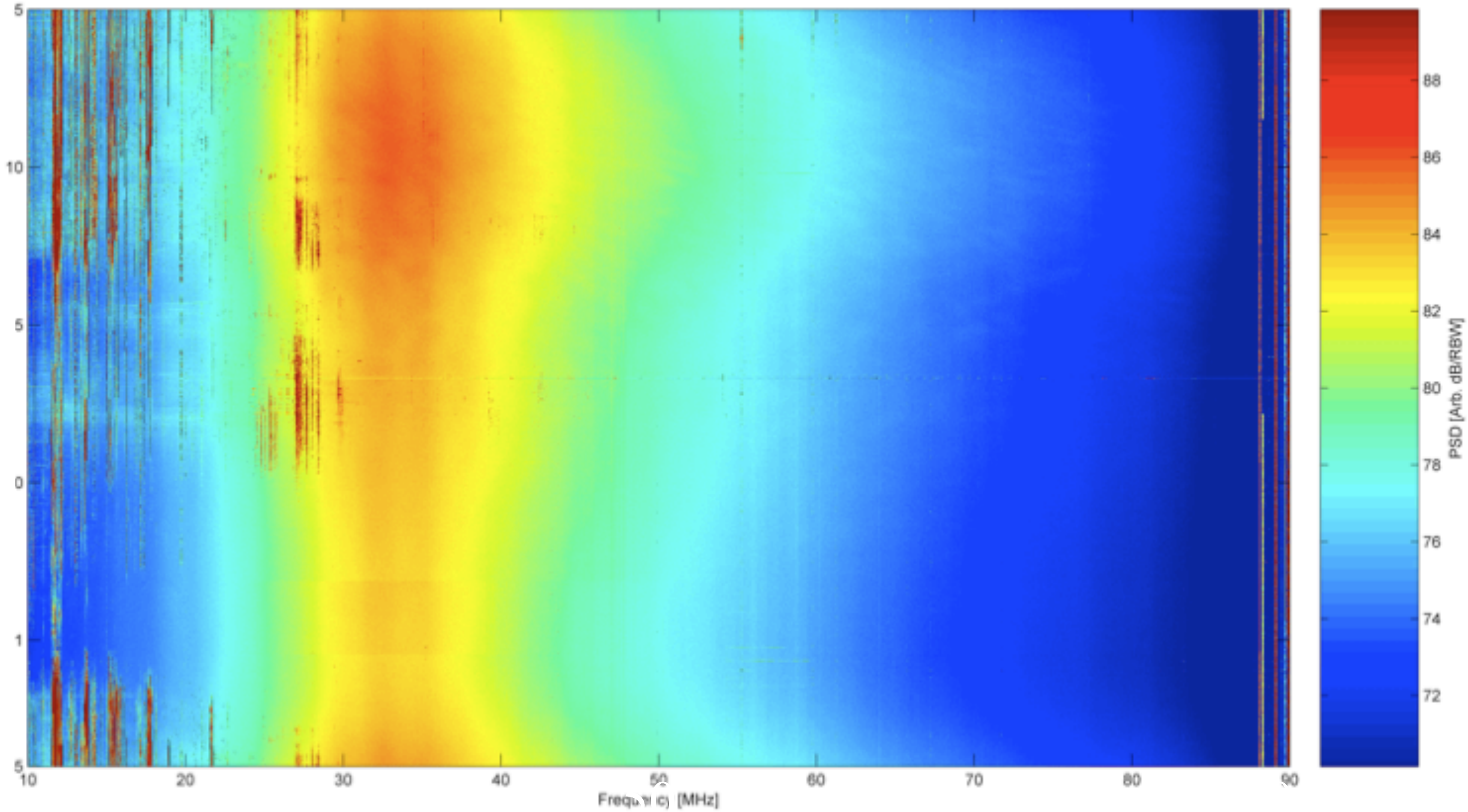
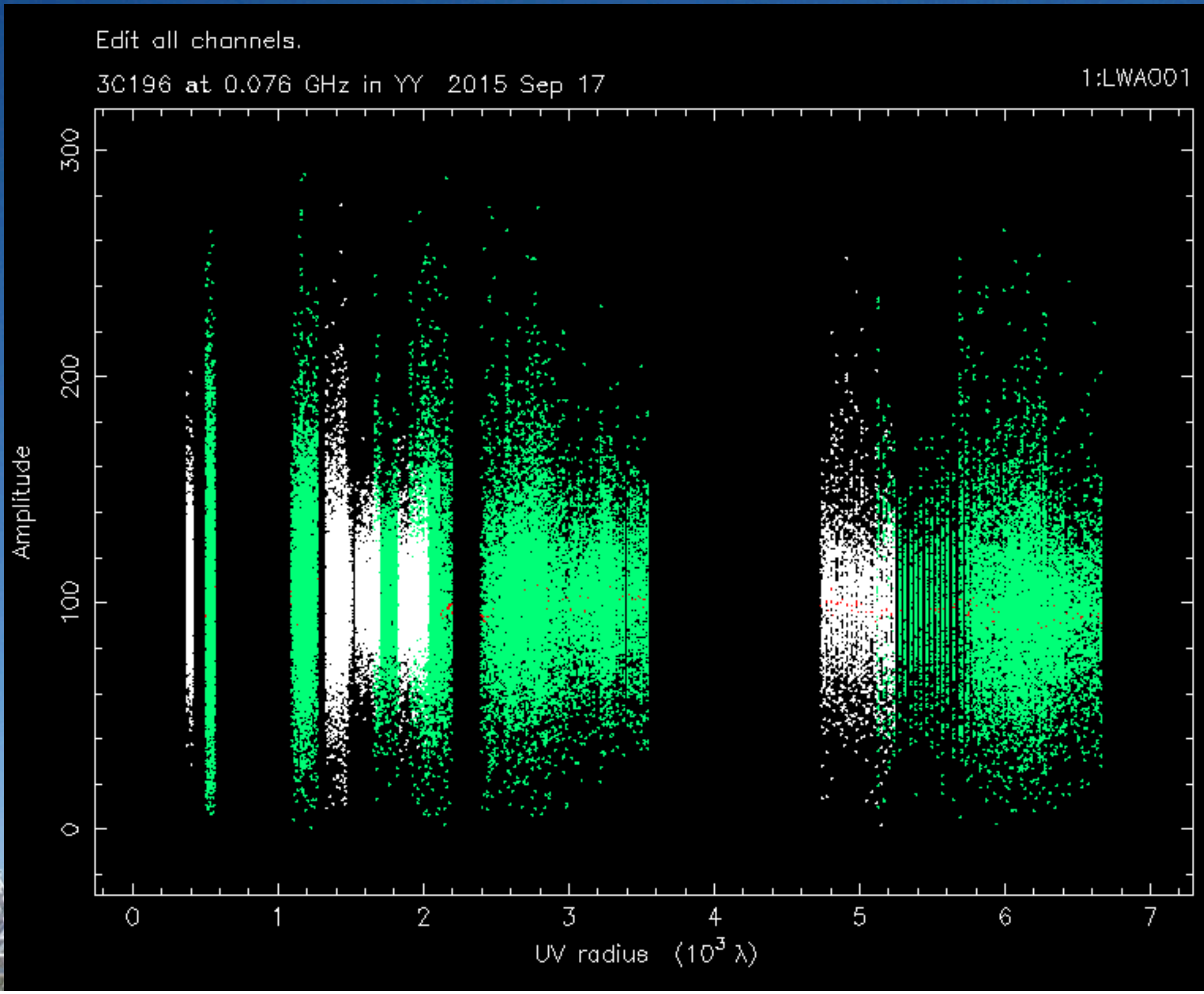


Figure 4: Spectrum using the TBW capture mode for 20 dipoles phased at zenith for 24 hours. The time and frequency variation of the background are real; the contribution of the active antenna appears as a steep role-off below 30 MHz. Note that 30-88 MHz is always useable, and even frequencies as low as 13 MHz are usable for a few hours each day.

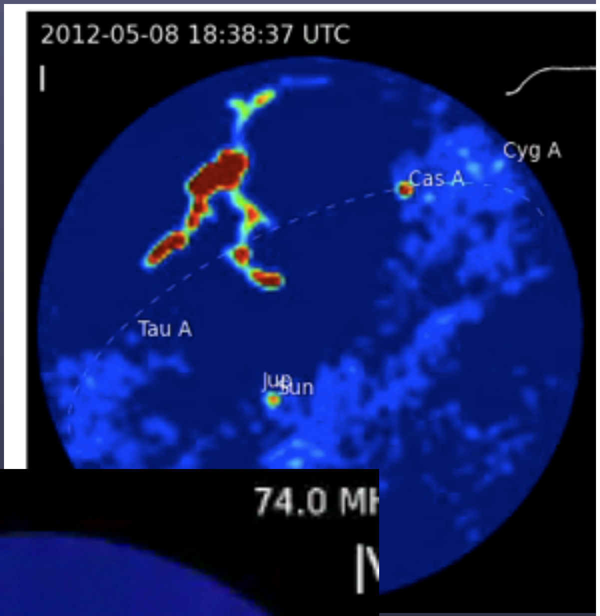
LWA
Long Wavelength Array

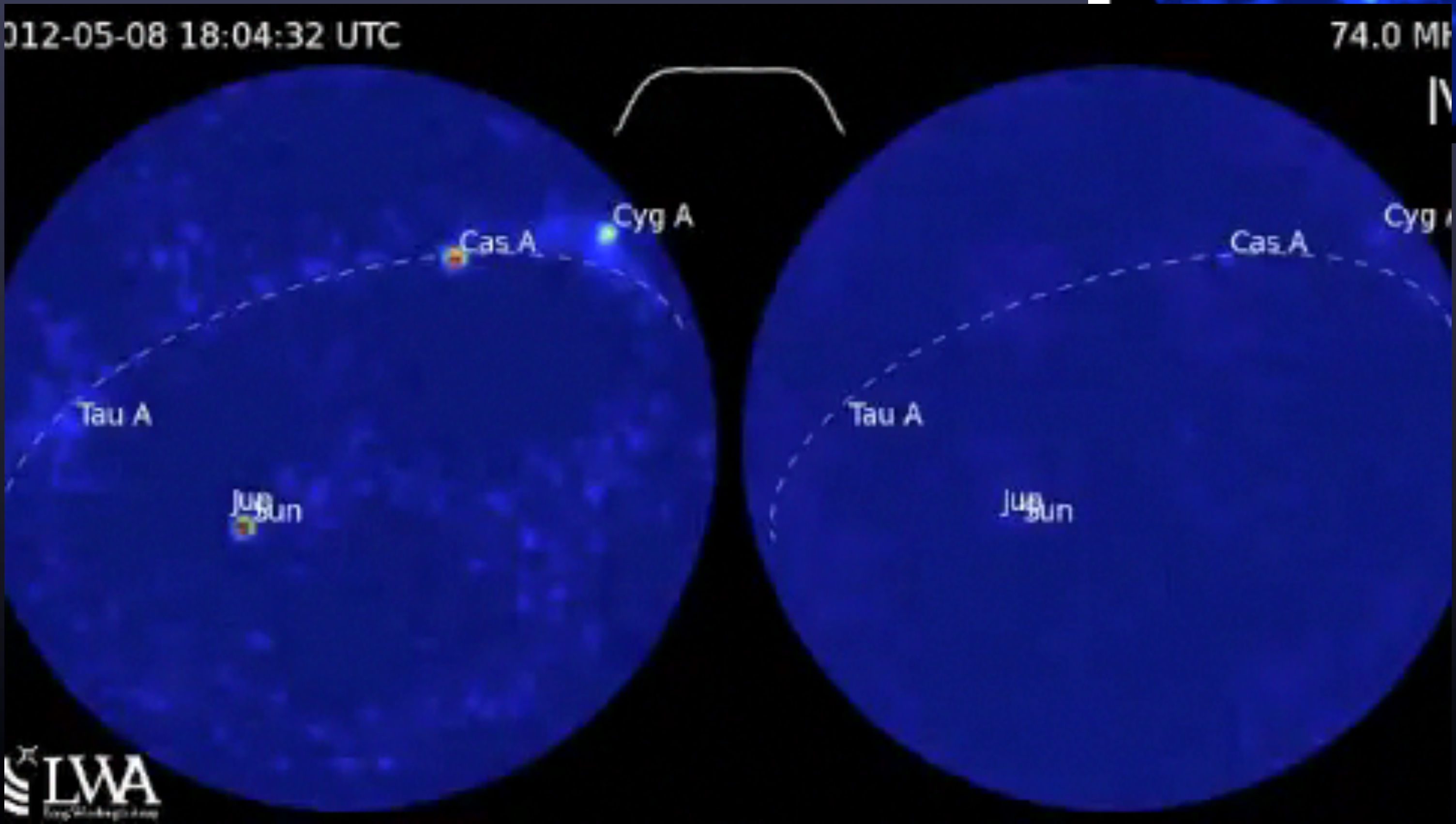
ELWA - Demonstration



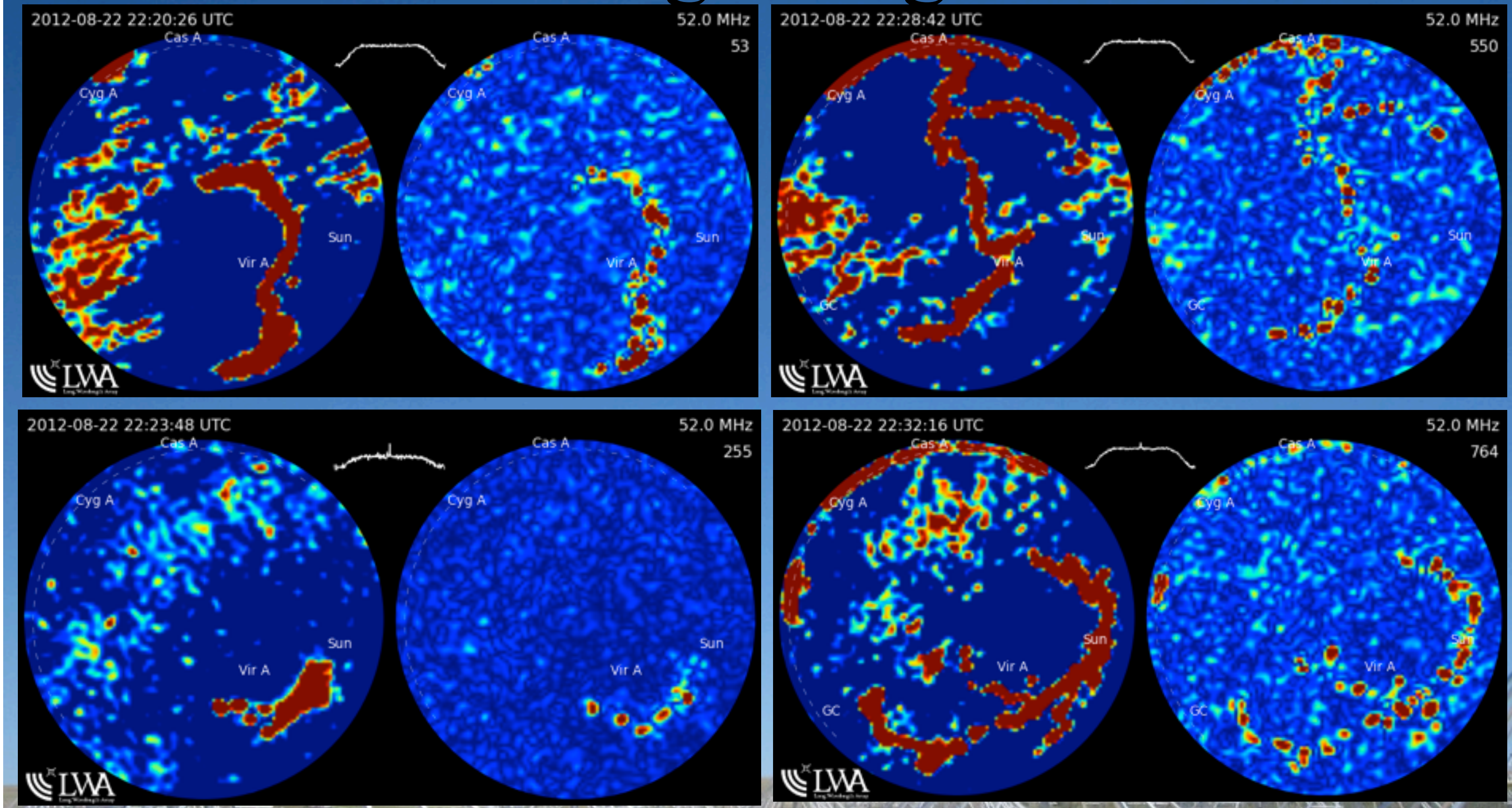
Lightning

Thunderstorm season on the Plains ...



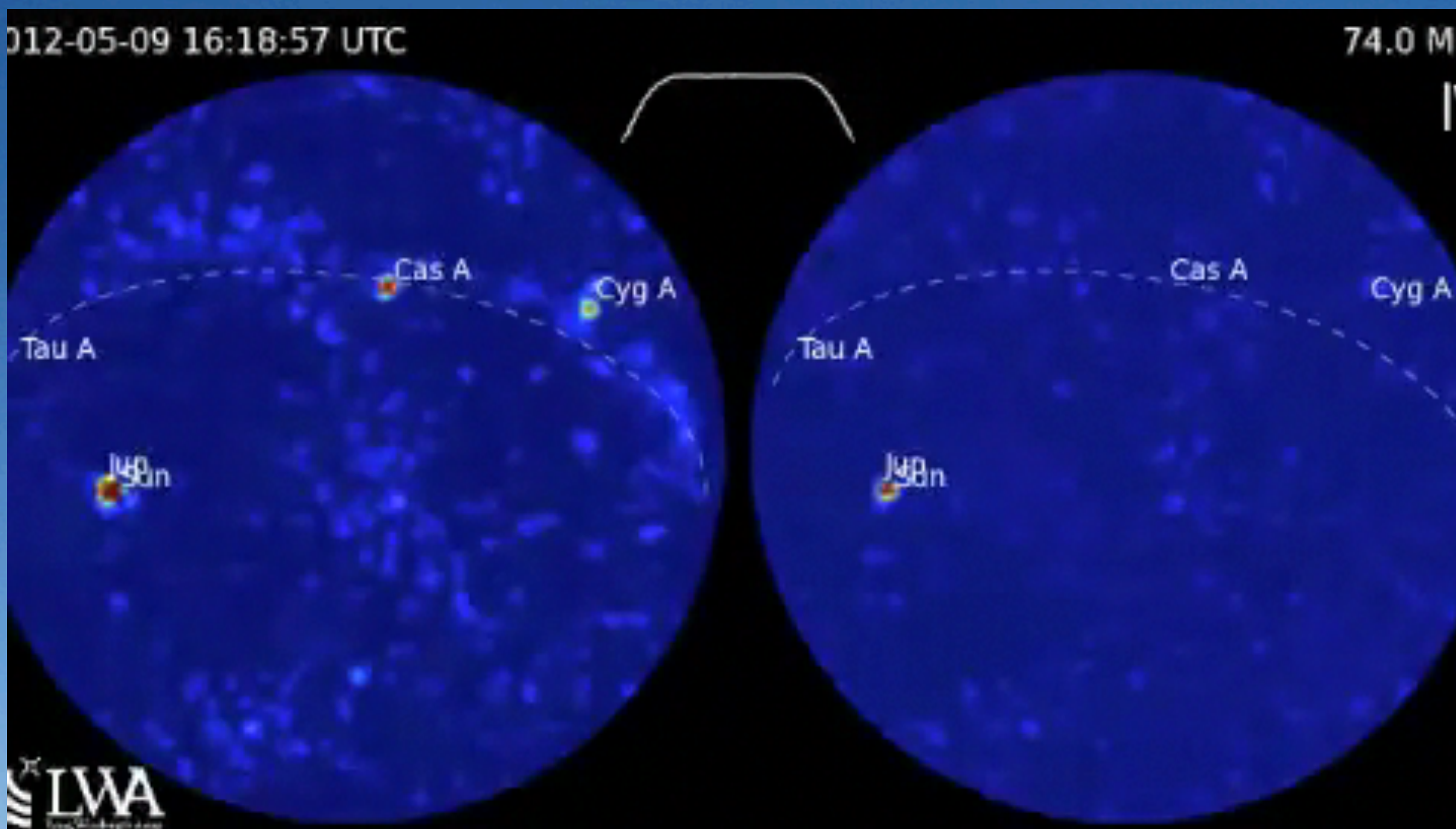


Lightning

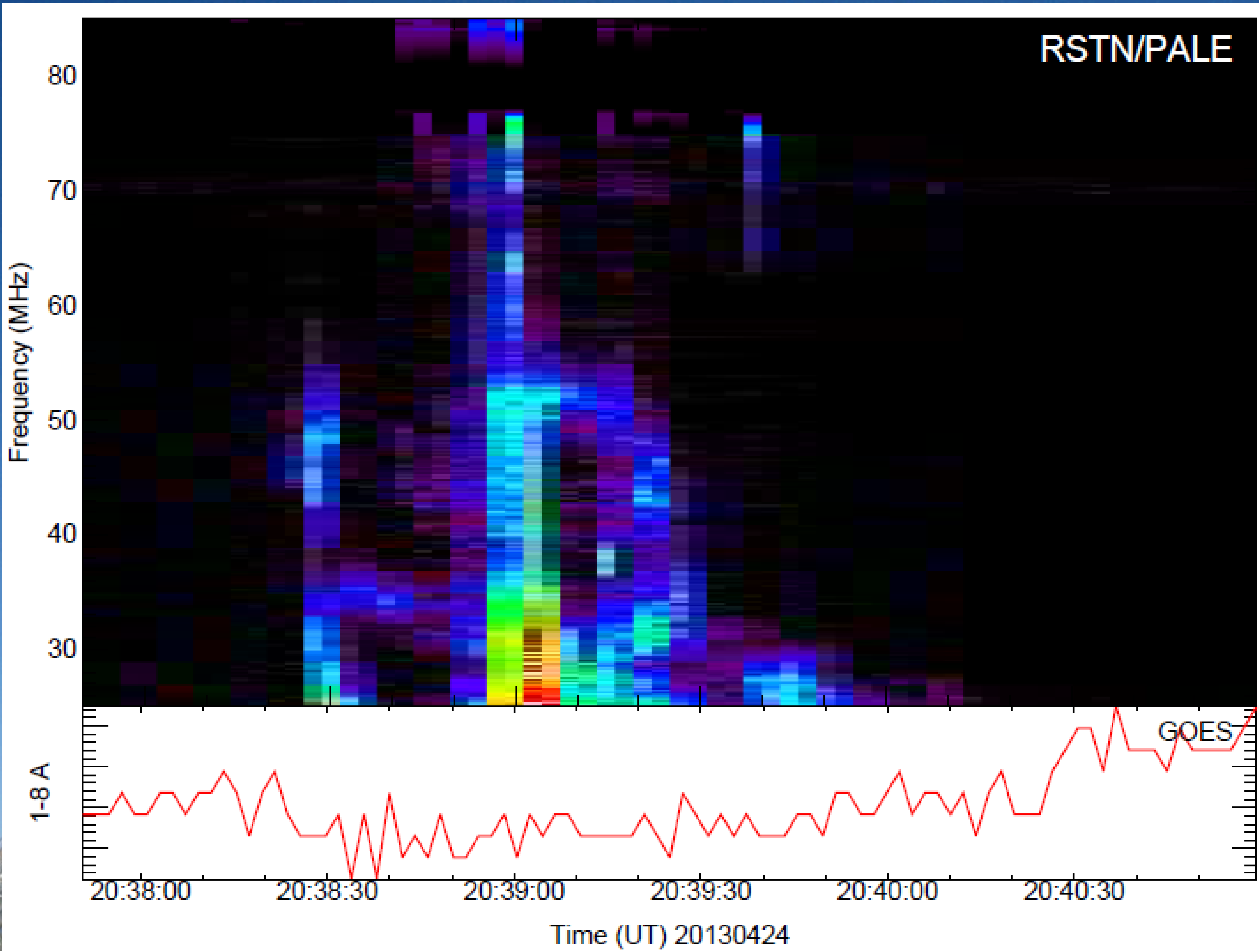

2012-08-22 22:20:26 UTC
52.0 MHz
53
2012-08-22 22:28:42 UTC
52.0 MHz
550
2012-08-22 22:23:48 UTC
52.0 MHz
255
2012-08-22 22:32:16 UTC
52.0 MHz
764
Cas A
Cyg A
Vir A
Sun
GC
LWA

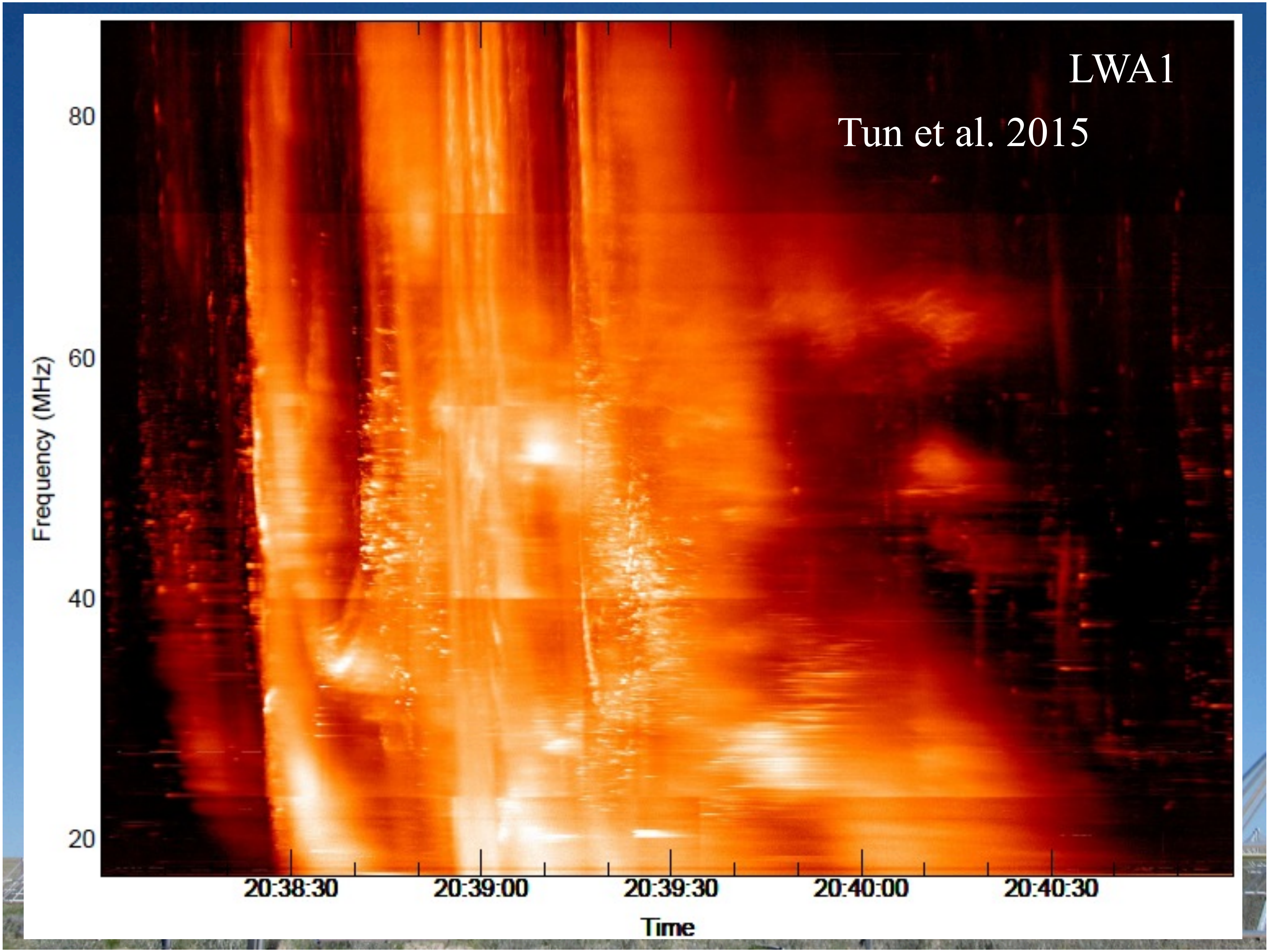
Solar Interference

Watch out for the Active Sun

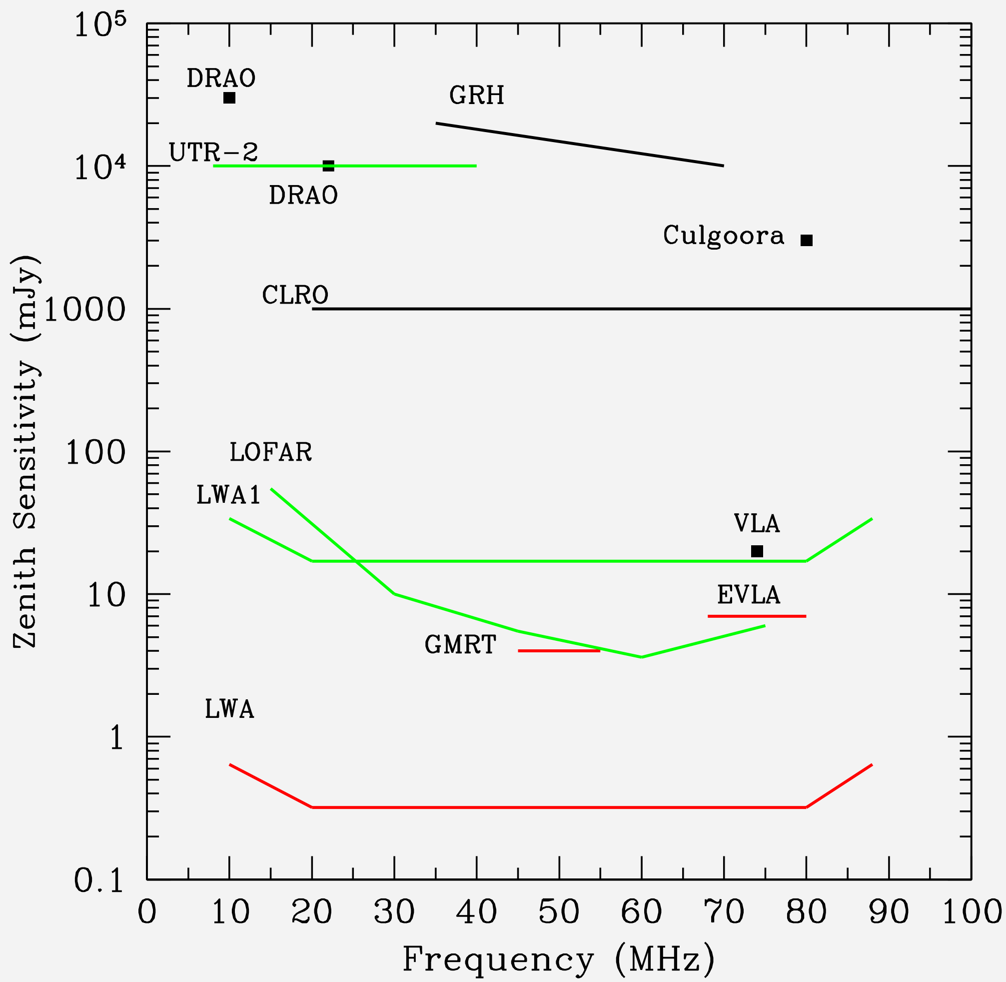


“Type III” burst at RSTN (3 seconds, 0.15 MHz)




LWA1
Tun et al. 2015
Frequency (MHz)
80
60
40
20
20:38:30
20:39:00
20:39:30
20:40:00
20:40:30
Time

Comparison to other instruments



Declination Range		Δν (MHz)
UTR2:	-30° to +60°	33
LOFAR:	-11° to +90°	16
Y=VLA:	-35° to +90°	3
LWA1:	-30° to +90°	16
GMRT:	-53° to +90°	10

LWA1 has sensitivity ~25% of all of LOFAR-LBA